metal
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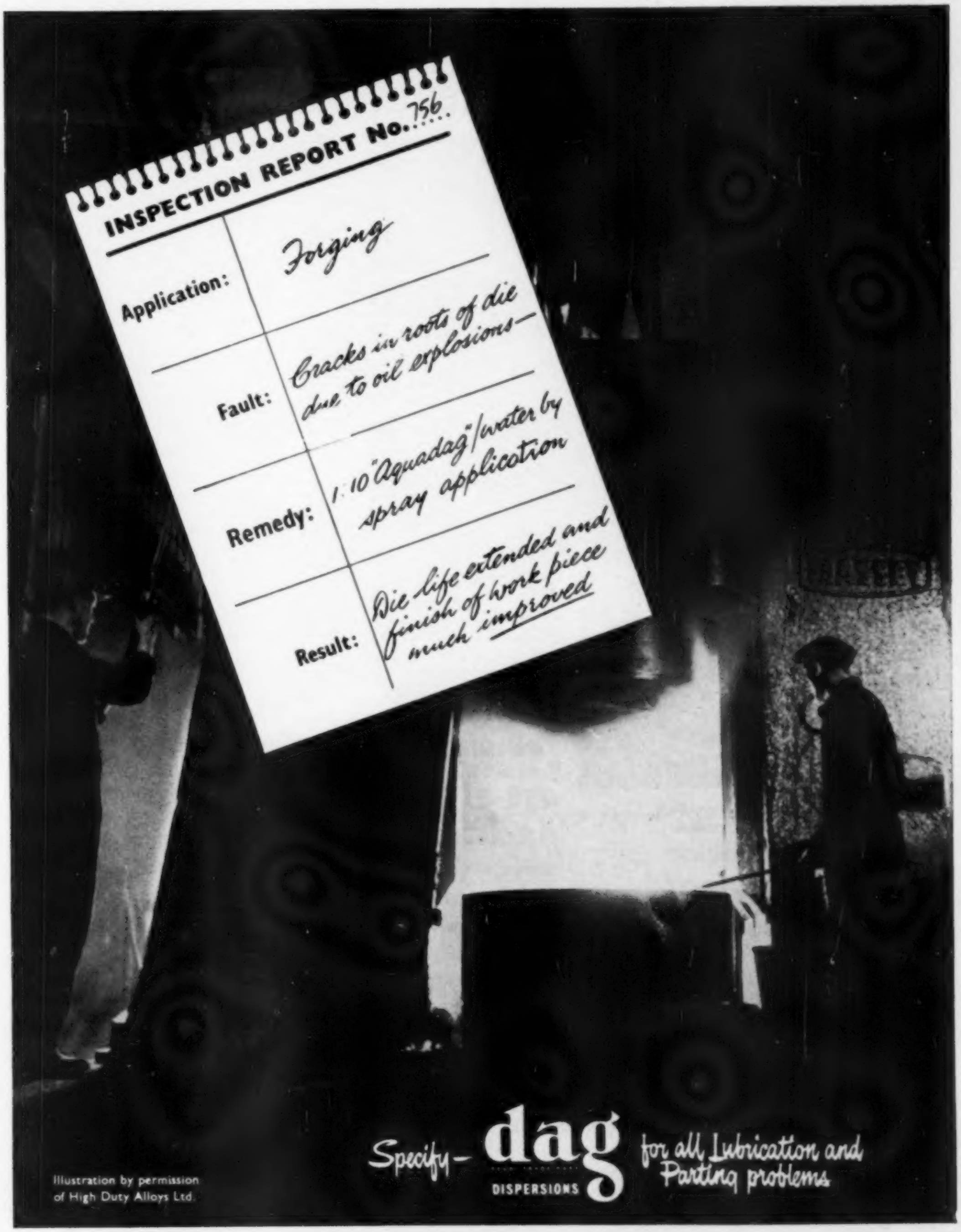
Vol. 25 : No. 155 AUGUST, 1958 Price 2/6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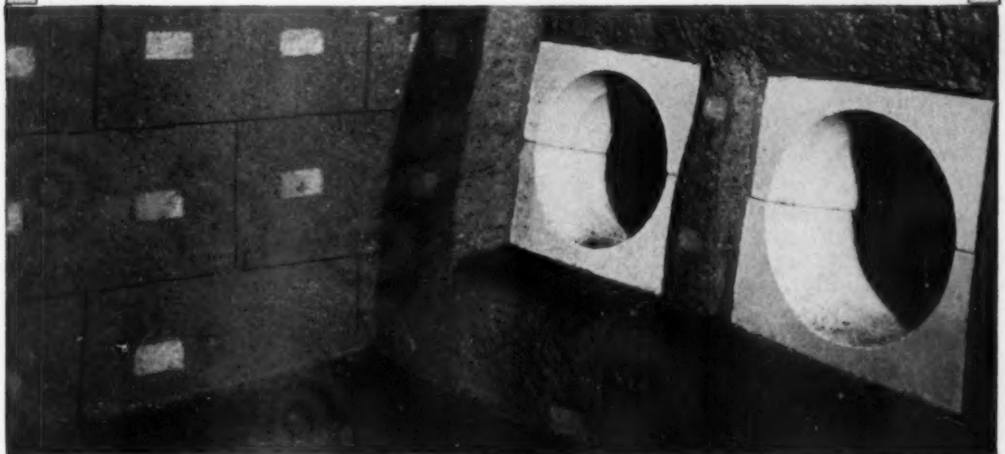

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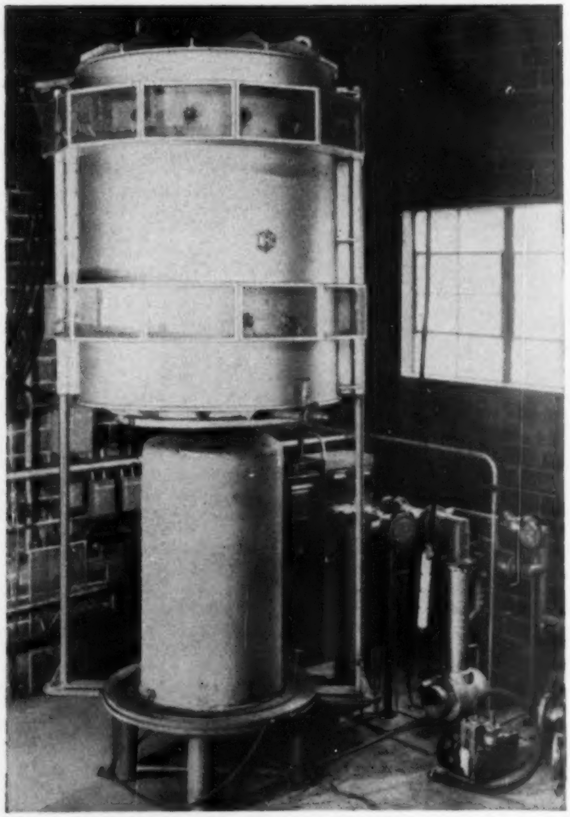

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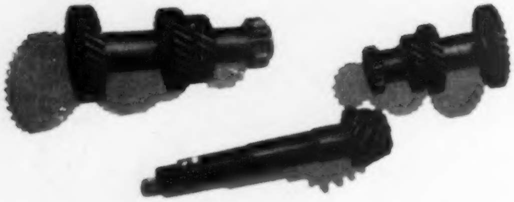

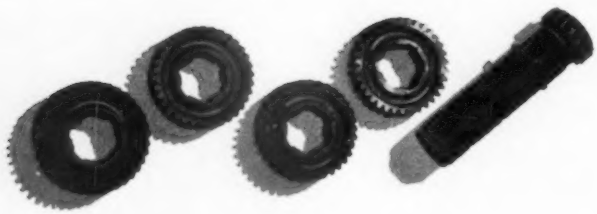

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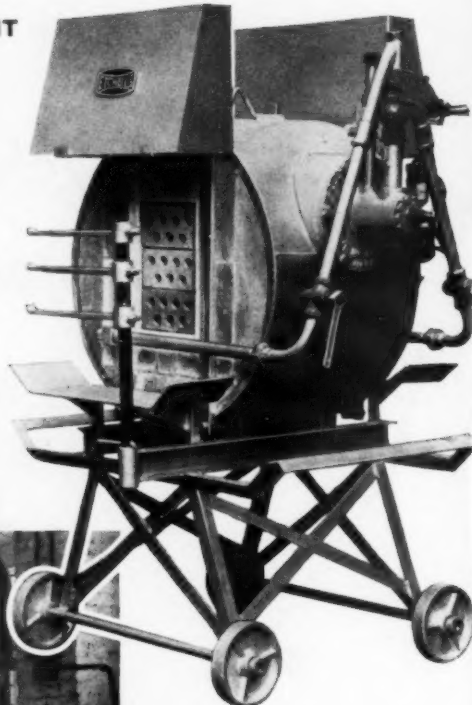

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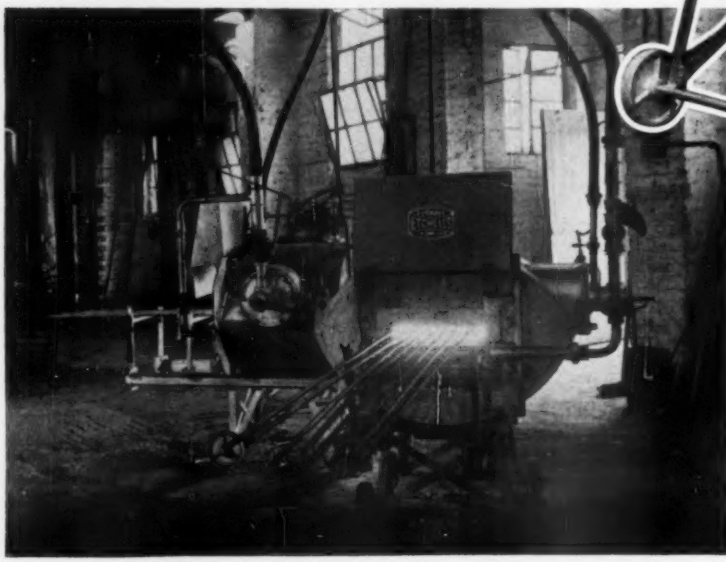

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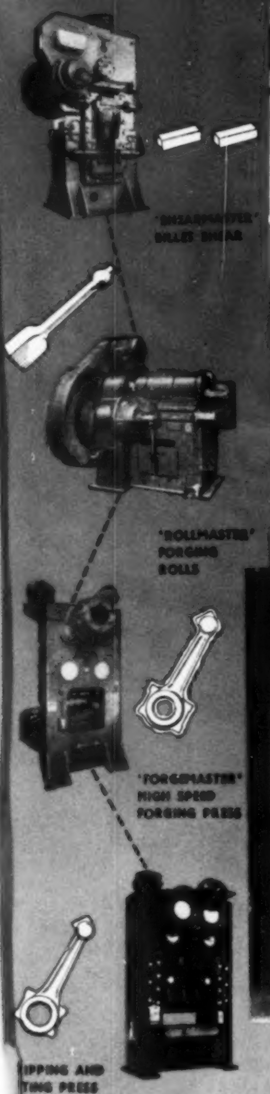

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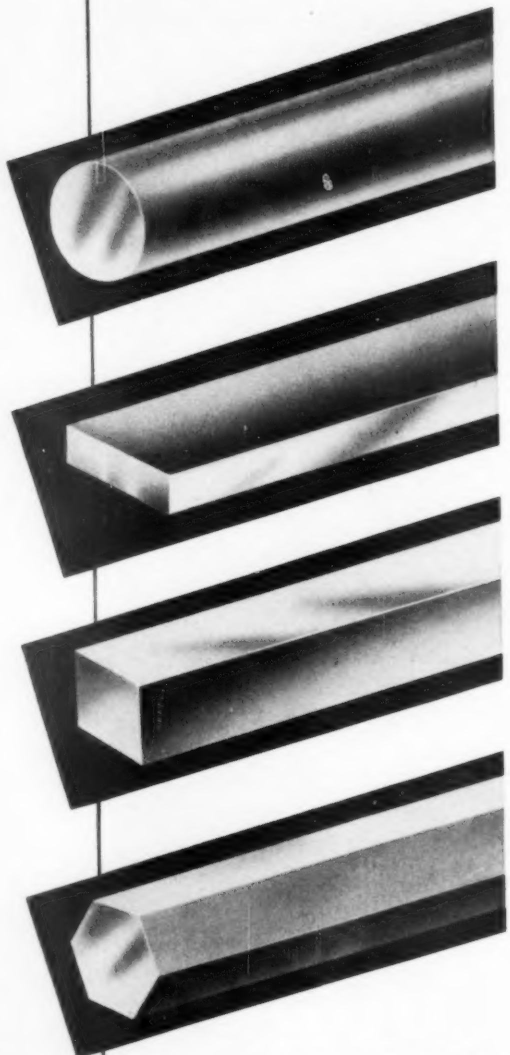
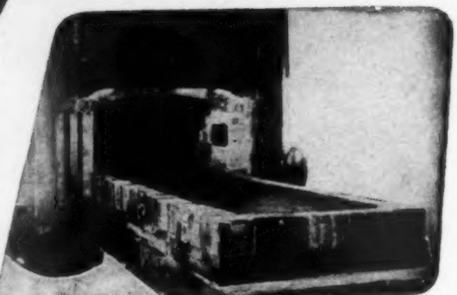


BOGIE TOPS

Examples of another of the many uses for REFRACTORY CONCRETE

Atlas Steel Foundry. Bogie for mould drying stove, topped with Refractory Concrete. Bogie is 25ft. long and 10ft. wide, the topping being 6in. thick. The door shown is lined with Ciment Fondu insulating concrete.



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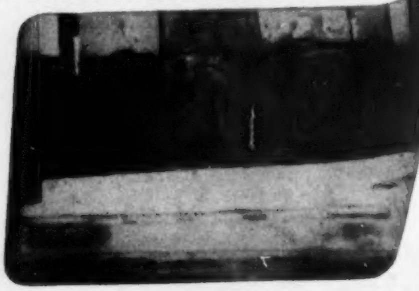
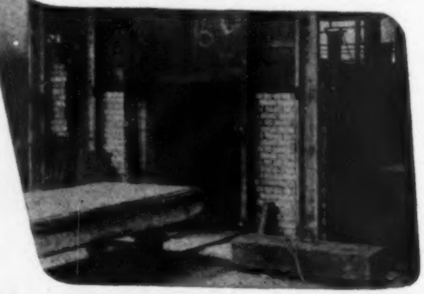
Bogie used at large Northern Foundry, in gas-fired tunnel oven, for annealing maleable iron at 1050° C. Bogie is 7ft. by 7ft. and the Refractory Concrete is 12in. thick.



Crossley Bros. Ltd. Bogie for gas-fired annealing oven operating at 650° C. The door is also lined with Refractory Concrete.



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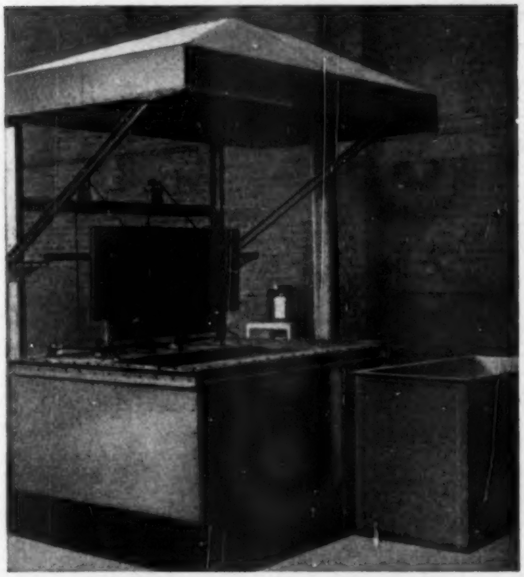

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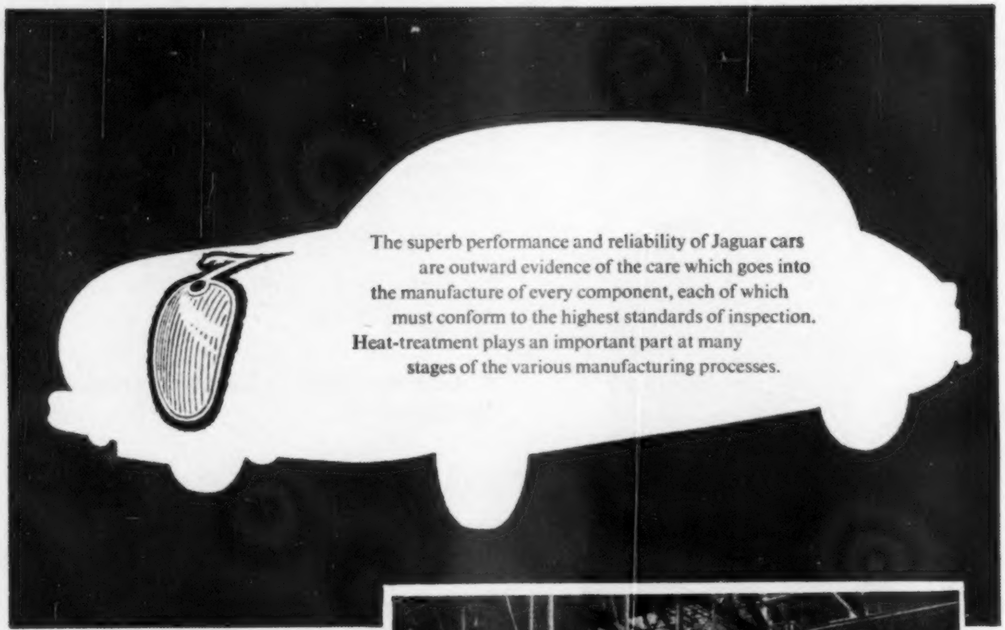
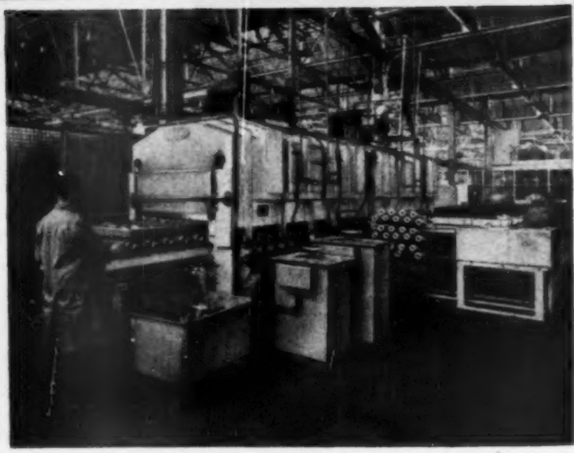
CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation, testing and protection, with research work and development in all these fields

JAGUAR AND G.W.B.





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APPLICATIONS

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General and particular

A FEATURE of industrial life during the past two decades has been the emergence, and the widespread acceptance, of the research association as a method of getting various investigations under way, pursuing them as long as they promise to be reasonably valuable and finally seeing to it that the results of such investigations are translated into some concrete development. Generally speaking, most research associations may credit themselves with a number of outstanding successes in this field, though there may well be also an uncomfortably large number of projects which have turned out to be either spectacular failures or, more likely, simply sterile, that is to say interesting to the investigators, and making a significant contribution to the sum total of scientific knowledge, but not immediately 'applicable' in the sense that they can lead to any notable industrial development.

A field in which industrial research associations may, however, play a most important, if not readily publicized, role has been recently brought to light by the publication of a small booklet entitled 'Small firms with big problems.' This has been issued by the Department of Scientific and Industrial Research and it tells briefly the story of an experimental Technical Liaison Service run by the Scottish Council (Development and Industry) in 1955-56 to help small and medium-sized engineering firms in the matter of information and the flow of information. The full findings of the investigation have been the subject of a much larger report issued by the Scottish Council in Edinburgh.

The experiment, which was undertaken in the central industrial belt of Scotland, sought to bridge the gap between research institutions and their store of valuable knowledge and the smaller-sized firms who might well make use of this knowledge but who lacked trained scientists or technologists to guide them to it. This is not the first time by any means that this problem has been studied; several previous reports from other industrial centres have stressed the necessity of providing technical information centres with field officers covering a given region or locality, but only the Scottish study has actually set up such an organization and then examined closely how it operated in practice. During the time that the experimental Technical Liaison Service (the T L S) was in operation a total of 109 smaller-sized firms were assisted and solutions were sought to 223 problems which the firms could not overcome with their own resources. Of the 153 problems successfully answered by the T L S, 80 were accepted by the firms as the basis of some new departure in organization, technique, or manufacturing method. Roughly speaking, three-fifths of the questions answered were technical in character, and the other two-fifths were organizational.

Now, all the findings of the Scottish investigation, covering both types of problem, are too many and varied to be considered in detail here, but they all added up to one conclusion—that there is a tremendous gap between small and medium-sized firms and potential sources of information. Written publicity from research bodies, says the report, has been shown to be a totally inadequate substitute for personal contact or recommendation. The shortage of technical staff in many firms often makes it difficult for them to apply the general theoretical findings received from many research and information organizations; a permanent technical liaison service would perform a valuable function for both firms and sources of information.

To the T L S itself (during its brief period of existence) it is stated that three research associations proved outstandingly useful, namely the British Cast Iron Research Associa-

Beryllium

Rapidly increasing importance of a rare metal for atomic uses

In the field of nuclear energy the Atomic Energy Authority is so confident that developments in this country will depend on gas-cooled reactors as at Calder Hall that full-scale production has been called for in the case of two essentials. These are beryllium for fuel cans and uranium ceramics as fuel elements. This promotion of the rare metal beryllium provides a striking theme in industrial application of what the Americans called 'the metal from low-grade emeralds.' Despite high cost and a rarity emphasized by estimates of beryllium in the earth's crust as only one thousandth of one per cent, there has come the advanced gas-cooled reactor (A G R) in which beryllium is essential. The G E C is to build a new research laboratory at Erith entirely devoted to beryllium, while I C I is to develop extraction of the metal to the order of hundreds of tons annually. Even when by-product beryllium from mining felspar and mica is added to limited sources of hand-cobbed beryl ore, the problem of sufficient beryllium will add to other difficulties associated with what has been called 'the world's number one metallurgical headache.'

To appreciate the story of this rise to a strategic metal, a brief reference to beryllium's early history is appropriate. Pliny began the tale when he expressed the belief that beryl and emerald were near relations. Hauy verified this, so it was not surprising to hear of the analyst Klaproth boasting of using a Peruvian emerald for his search for a new element. But it was the French chemist Vauquelin who detected a new element, one prepared as impure metal powder in 1828. Only in the nineteen-twenties did beryllium appear in ingot form, a metal exceedingly difficult to work, yet attractive since it is only two-thirds the density of aluminium.

Though other exceptional properties soon became apparent (apart from its uses yet to come in the atomic field), beryllium posed its first problem in proving rare despite intensive prospecting for mineral resources. Occasionally the element appeared in huge crystals, one of which was 18 ft long and 4 ft dia. By 1947 production of beryl ore was approximately 3,000 tons, which yielded less than 100 tons metal, a figure beyond which nothing further has been quoted since the metal became 'strategic.' Occasionally, also, there would come a beryllium 'find,' as when a British corporal sauntered out of his geology lesson provided by the R.A. Educational Corps in Hong Kong in 1956, and hit upon a rich vein of high-grade beryl.

An even greater problem than the sporadic supply of beryl is the extreme difficulty of working pure beryllium metal with its high fusion-point and a high vapour pressure just above this point. Not only are beryllium derivatives so toxic that special precautions have to be rigidly enforced, but the metal can only be hot-pressed in a vacuum, rolled, extruded or fabricated while enclosed in a steel sheath or 'can.' Beryllium metallurgy was not so difficult, while alloys with copper and nickel were produced as chief applications. Beryllium-copper containing only 2% of the rare element showed such striking qualities that it would not have been surprising if all beryllium production had gone into this alloy, which is six times as strong as ordinary copper, outbids phosphor bronze, shows no sparking properties in dangerous atmospheres, has a high electrical conductivity and corrosion resistance, and increases the life of instruments a hundredfold. Beryllium-nickel, again with only 2% beryllium, is invaluable in heavily-stressed aircraft parts, and beryllium-nickel steels or iron alloys are widely adopted in Swiss watch factories and elsewhere.

Uses of the unalloyed metal

All this appeared to determine the position and potential applications of beryllium for decades to come, until unalloyed beryllium metal suddenly took the limelight. The metal had been used at times for neon sign electrodes, while in windows for X-ray tubes it proved invaluable, since with its low atomic weight it outbid aluminium with a transmission 17 times greater.

In the atomic energy field all the claims for beryllium have proved well founded—claims for it as metal superior to all others as moderator or reflector of neutrons. There is also a high corrosion resistance in reactors cooled by carbon dioxide, such gas cooling being preferred in this country for higher temperature operation. With fuel cans of beryllium enabling a working temperature of 600°C a gain of 100° is achieved over temperatures possible with other metals.

When 160 years ago Nicolas Vauquelin, who had begun his chemistry as bottle-washer in a Rouen pharmacy, discovered a new element in emerald, he began a story which has taken on new facets never imagined in that serene era in chemical history.

tion (B C I R A), the British Welding Research Association (B W R A) and the British Iron and Steel Research Association (B I S R A). Significantly, the first two of these had local representatives in Scotland which enabled them to give more direct and practical replies than some of the others, and it is the opinion of the investigators that B I S R A could profitably appoint local permanent staff.

The findings of this Scottish survey underline a fact which is not always appreciated as clearly or as widely as it might be; namely, that National industrial development as a whole proceeds more often than not by a series of small local advances rather than by a major ' push ' on a broad front. Every now and then it is true, something in the nature of a revolutionary upheaval does take place and some new product or new process is born, usually after a protracted and difficult labour which only firms with big resources behind them can contemplate. The work of a research association may or may not play a major part in this kind of development; we suspect that the part played is not always as great as some protagonists would have us believe, but be that as it may, it is evident now that of equal if not greater importance in the long run are the innumerable little bits and pieces of assistance to small firms which a research association, properly equipped with liaison personnel, can render.

It must be recognized at the same time, however, that work of this kind may not always be altogether attractive or satisfying to research association personnel. Quite rightly, the accepted forms of scientific and technological training in this country lay the major stress on the study of fundamental principles. A mind which cannot readily grasp these principles, or appreciate the beauty of mathematical analysis applied to problems of physics, chemistry and their related offshoots, is not the mind of a scientist. After three or four years at a university in daily contact with this kind of thinking, it is hardly surprising that the graduate scientist constantly feels drawn to continue thinking along the same lines, and believing that industrial development should arise from ' fundamental ' research. But the brutal fact remains that in nine cases out of ten, industrial progress is made not so much by the application of scientific knowledge as by what can only be described as ' inspired tinkering.' The problem worrying firm *A* is often answered most successfully, not by the theoretical scientist, but by the man who knows how firm *B* got over some similar trouble, and who can quickly see how firm *B's* experience can be adapted to help *A*. Knowledge of the particular, in other words, is often far more valuable than knowledge of the general.

A perfect example can be cited, namely, the use of ferro-silicon-chrome to deoxidize and recover chromium from the slag in the electric-arc furnace after refining a charge of stainless steel with the oxygen lance. Prior to 1950 this was normally carried out in Britain with ferro-silicon, followed by a make-up addition of ferro-chrome. It was realized, however, by an officer of B I S R A (now the present editor of this journal), that the operation was essentially the same as that used in the final stages of the Perrin process for the production of low-carbon ferro-chrome, and that therefore the ternary alloy should do the job just as well and more quickly. Some ferro-silicon-chrome was obtained and, sure enough, it proved to be a notably better and cheaper way of completing the operation.*

The point to note is that the B I S R A officer did not hit on this scheme owing to his knowledge of general metallurgy; he did so because eight years previously he had been employed in Britain's only Perrin plant and was therefore one of the few men in the country who knew that ferro-silicon-chrome existed and what it would do when added to a basic, chrome-bearing slag. A lifetime spent in a fundamental research would not have given him this, at the time invaluable, piece of information.

**This technique is fully described in ' Iron and Coal Trades Review,' September 29, 1950, (161), 525-528.*

Drop forgings to suit the final machining

Prof Dr Ing OTTO KIENZLE

The following article is a translation from the German of the author's contribution to the Seventh Mechanical Engineering Congress held this year at The Hague. It is pointed out that the drop forging as delivered by the drop forger must suit the final machining process by uniformity of hardness, toughness, etc, and therefore it is important that agreement be reached between the designer, the drop forger and the finish-machiner as regards optimum tolerances and machining allowances. These will, of course, vary according to which method of machining is chosen. It must also be borne in mind that drop-forged items with cold-pressed surfaces will already possess the necessary finished accuracy in certain dimensions. Professor Kienzle is head of the drop-forging laboratory at the Technische Hochschule, Hanover, Germany

THE ROLLED METAL which is to be made into tools or other machine components is obtained in various forms from the rolling mills. The commonest at the present time is rolled bars from which a considerable quantity of material must be removed by turning, boring, planing and milling. The finished form is approximated closest by material which has been cold formed in the forge from the rolled bar, and which only requires a small amount of machining; the possibility of this is limited by the malleability of the material and by the expenditure on tools and machines.

Between these two groups, with respect to the approximation to the final shape, there is the hot-deformed drop forging, which is manufactured from a length cut from the rolled billet. Compared with the rolled bar, it has the advantage that it can often be brought as close to the final shape as by rough machining, but it requires heating, the die and the forging machine. Compared with the cold deformed piece, it has the advantage of less deformation resistance and thus smaller power requirements and cheaper machines and tools, but it does not reach the same accuracy of measurement and therefore requires more final machining.

When we discuss the question in which way the drop forging can be made to suit the final machined item, it seems expedient to consider this in competition with the processes just mentioned and with a further competitor—the high-precision castings in high duty alloy—whether it be in steel or non-ferrous metal.

The finishing process of the forging differs greatly accordingly to its purpose. In many cases, this consists only of a polishing-off of the flash, or polishing before galvanizing. To this end, it is important to forge the item with the highest smoothness of surface and to de-flash it cleanly. This is economically important, since otherwise the grinding costs can become too high with respect to the forging costs; we are thinking, for example, of tools such as pincers, hammers and spanners.

For components for machines and plant we will divide the surfaces into the following groups:

(*A*) *Surfaces which can be forged so clean that they require no further machining* These must have surfaces which are both macro-geometrically correct (round, smooth and even) and also micro-geometrically free of faults. These surfaces will be better according to whether the die is less worn and the scale is fully removed.

(*B*) *Surfaces which are only to be smoothed by a rough grinding* This concerns mostly those in which the flash-line lies, is left on, but also those which are very rough because of die wear.

(*C*) *Surfaces which are to be machined* In this there is the duty that the machine cut over the whole area machined must be as uniform as possible for all the items.

There is no question that we must endeavour to transfer as many of the cases from surfaces of group (*C*) to group (*B*), and from group (*B*) to group (*A*).

The comments which follow refer to items of group (*C*) which are to be machined and, in fact

New magnetic steel

Comparison of crystal arrangement in conventional and new magnetic steel

WESTINGHOUSE RESEARCH LABORATORIES in Pittsburgh, U S A, recently announced a new kind of magnetic steel called 'Cubex.' Described as 'doubly-oriented silicon-iron,' or 'cube-oriented silicon-iron,' it is expected to be used in the magnetic cores of electrical devices such as transformers, motors and other electrical equipment. The metallurgical processes involved in preparing the new silicon-iron were originated at the Vacuumschmelze of Hanua, Germany—a division of the Siemens-Halske Co.

In preparing the new material, Westinghouse claims to have discovered a new mechanism for crystal growth in metals. As a result, the new silicon-iron has a unique crystal arrangement, contrary to that normally encountered, and difficult to bring into being. The crucial characteristic imparted to the new steel by its unusual crystal orientation is an ability to be magnetized easily in four directions. This permits magnetism to readily 'turn corners' in the magnetic core of a piece of electrical equipment.

Hot-rolled unoriented silicon-iron—the first true magnetic steel—was introduced into the electrical industry at the turn of the century. Then came singly-oriented silicon-iron, called Hipersil, which was developed and pioneered by Westinghouse and the American Rolling Mill Co in the 1930s. It represented a major advancement, and Hipersil-type iron still remains the best core material in large-scale use today. Considerable work still must be done in 'scaling up' the new Cubex steel and finding the best ways of using it.

Cubex steel has about the same chemical composition as the standard magnetic variety—about 3% Si to 97% Fe. The real difference arises from the way the steel is handled during its processing from rough sheet into the final product. The process responsible for producing cube-oriented silicon-iron has been shown to be operative in sheets thick enough to make it feasible for use in large transformers and motors. Thin strip, which is much easier to prepare, has been made on a pilot-plant scale. Such strip, about 1/5,000 in. thick, is of the dimensions used in airborne transformers, relay cores, and similar electronic and electrical equipment.

Crystal arrangement

The new cube-oriented silicon-iron is obtained by reorganizing the crystal arrangement normally found in the metal. Atoms of iron are arranged in such a manner that they form crystals in the shape of tiny cubes. The direction along any edge of the cube represents an easy path for magnetization; directions across any face of the cube, or diagonally through it, represent difficult paths. Therefore, to have a good magnetic core material, these tiny cubic crystals must be oriented in the metal.

The crystal arrangement in a sheet of the new cube-oriented magnetic steel might be compared to the arrangement of a tray of ice cubes. Each cube rests flat on one side and squarely faces the ends and sides of the tray. Therefore, the edges of each cube are exactly aligned with each other and are always parallel to the ends (width) and sides (length) of the tray. Since the cube edges represent easy directions of magnetization, good magnetic paths exist along both the width and length of the sheet.

In contrast, the crystals in ordinary singly-oriented silicon-iron are so arranged that only the lengthwise path exists. It is as if the ice cubes all face one end of the tray as before, but instead of resting on one face they stand on edge. In such case, the only cube edges parallel to a surface are those aligned with its length. In a sheet of this steel, length represents the only easy path of magnetization.

Unoriented silicon-iron has a random arrangement of crystals in which the individual cubes occur in a 'hodge-podge' of geometric positions.

The deviations of dimensions of drop forgings depend on the die sizes and on the heat shrinkage. The latter remains more uniform the less the temperatures of the forgings vary; in this respect we are in the middle of a favourable development, since great attention is being paid to uniform heating on the grounds of forging, and ever greater use is made of electric induction heating.

The accuracy of the die has increased in recent years, in particular with the use of automatic contour machines. The thing that damages this accuracy, however, after short use of the die is wear. Since this increases with the number of items, the deviations of size increase with the number of forgings forged in the die; in this respect the dimensional tolerance is a question of economy and of price. The larger the dimensional tolerance the more items from one die and thus the cheaper the forging. We can limit this tolerance range if we counteract wear. Means to this end are:

The liquid-honing of die shapes.
Chromium-plated die shapes.
Insertion of wear-resistant high-duty die steel.
Scale-free heating.
Suitable lubricants.

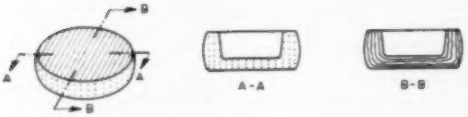

Fig.5: Direction of fibres in hollow bodies

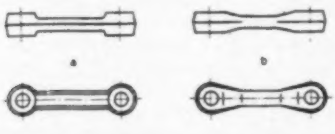

Fig 6: Arrangement of forgings with correct direction of flow
a) Sharp corners - large wear
b) Gradual taper - low wear

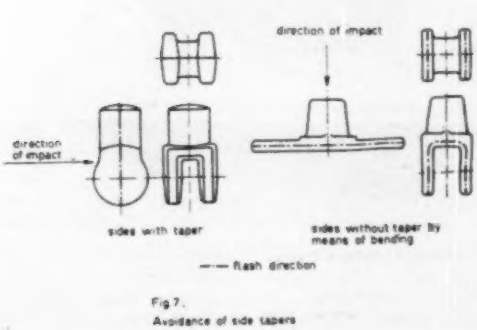

Fig 7. Avoidance of side tapers

There are in a number of countries standards for dimensional tolerances; a new standard for drop forgings from aluminium has just been prepared in West Germany. The manufacturer should ascertain whether compliance with the standard specification is stipulated in the contract. Concerning special agreements, it is recommended that the manufacturer be given a drawing of the forging stating special tolerances, the other dimensions being to the general standard. The client must be aware that with any decrease of a tolerance the manufacturing cost and the price are increased. Conversely, a cheaper price is possible if certain recommendations of the forgemaster are followed with respect to shape. A simple example is shown in fig 6; if the designer permits an alteration of the shape 6*a* to that of fig 6*b*, then there is a decrease of the wear and thus either higher accuracy for the same price or a lower price for the same accuracy.

The dimensional tolerances T are known to depend closely on the quantity of excess material Z; if the minimum excess material Z_{min} is exceeded by $+z\%$ then,

$$T = \frac{z}{100} \cdot Z_{min}$$

Assuming that z is a fixed amount for a particular process, *e g* turning, then T is proportional to Z. Large deviations in the dimensions of the forging, therefore, necessitate much excess material, which is undesirable on account of excess weight and the machining required. z will be small if the forging is to be machined in automatics; a forging suitable for automatics is one in which the value of z is small.

We shall see that Z, too, assumes different values according to what machining method we are considering. The excess material Z varies also for other reasons. One of the main reasons is the draft of the die; if for a round forging the skew of the die (referring to the diameter) is $1 : k$ and it is 1 mm long then the excess material from front to back is increased by

$$\triangle Z = \frac{1}{2k} .$$

Therefore low values of skew (large values of k) are to be aimed at. Sometimes one can so arrange the forging method that all draft is avoided (fig 7). Holes are best pierced cylindrically on a horizontal up-setting machine. Also, one can decrease the amount of material to be machined off by forging in two directions (fig 8).

From the forging point of view, the number of items to be made plays a large role. The larger

—in the experience of the author—particularly to steel. The condition in which the items are delivered shall be evaluated from two points of view: (*a*) quality of material and (*b*) dimensions.

Internal properties of the forging

The quality depends, in the first event, on the material which has been ordered by the forge from the rolling mills. This material, however, is altered during forging. According to the forging temperature, the grain size and structure are altered; both these are very important with regard to the strength which the material must have in use. For subsequent machining, the hardness shall be uniform and the structure shall ensure a satisfactory chip, as well as a high life for the cutting tool. Although very high temperatures (up to 1,200°C) in isothermal annealing give a very good structure for tool life and surface property, this method is not economic. Good results are obtained with isothermal annealing at approximately 1,050°C. If the forging is to be delivered annealed then of greater importance is the uniformity of every item; nothing is more unpleasant in final machining than varying degrees of hardness.

Freedom from cracks as the result of excessive deformation in the die must be ensured by one of the well-known testing methods; in particular, every single vehicle component which is responsible for the safety of the occupants must be investigated, and the testing device itself must be checked for correctness of indication, from time to time, with the standard test-pieces. As well as cracks, so-called cold shut (lap) must be avoided. This is a point which the manufacturer can influence greatly by correct choice of the original shape, and by selection of the intermediate shapes. They occur when material which is flowing is forced from two sides towards a single point; such laps occur sometimes in the flash and often extend into the forging (fig 1).

A further point of the natural properties of drop forgings is the direction of the fibres; also in this respect, the manufacturer has an influence when cutting from the rolled bar, and by choice of the forging processes. The fibre problem is, to my knowledge, not yet sufficiently explained. We know that the notch strength of one and the same material is appreciably less when the fracture plane (that in which the break occurs) lies parallel with the fibres, compared with when it is at right-angles to them (fig 2). The drop forger should therefore be informed in which direction alternating loads occur. With running surfaces which are stressed by rolling loads (*e g* gear wheels, roll journal bearings and rolls) the fibres must never run at right-angles to the stressed surfaces, but at least parallel with them and, if possible, also in the direction of rolling (fig 3).[2] It is clear from this that a gear wheel made from a forged blank is better than one milled from the solid, and a gear wheel with forged teeth is the best. A drop-forged item can have completely different fibre structures according to the position of the blank cut from the rolled bar relative to the direction of deformation (fig 4*a* and *b*). The pictures showing the direction of the fibres are sometimes inaccurate, as, for example, in the hollow forged item (fig 5).

Accuracy of dimensions

Although this point is the subject of many discussions between the manufacturer and user, it will not be treated here in full, since the author reported on this at the Fifth International Congress of Iron and Metal Users' Industries, 1953, in Turin. We will repeat the general conditions and then go into the requirements of individual machining processes.

GENERAL CONDITIONS

Concerning deviations of dimensions we distinguish: (*a*) dimensional deviations, (*b*) deviations of shape, and (*c*) deviations of position.

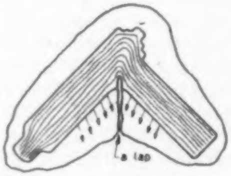

Fig.1
Occurrence of a lap

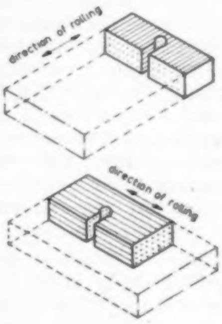

Fig.2.
Taking of notch test pieces
a) Plane of impact parallel to the fibres
b) Plane of impact at right-angles to the fibres

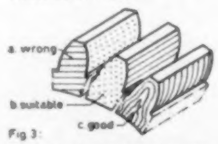

Fig 3:
Direction of fibres in gear wheels of different methods of manufacture
a) Teeth cut from flat steel
b) Teeth milled from billet of round bar
c) Forged teeth

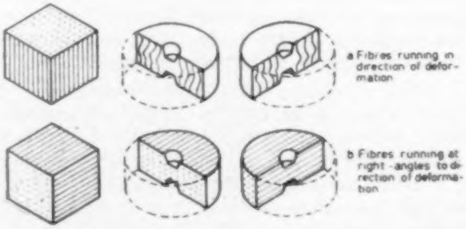

Fig.4
Direction of fibres in discs

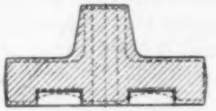
— Suitable for reference surfaces
--- Unsuitable as reference surfaces on account of deformation and wear of the die

Fig 13: Reference surfaces on drop-forged items

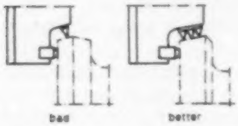

Fig 14: Position of flash to suit machining in a lathe

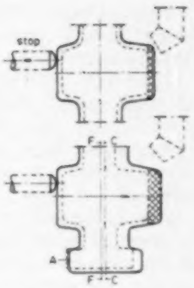

Fig 15: Facing of a drop forging: influence of uneven wear of the die. Forging symmetrical to C-C, finished item symmetrical to F-F. Point A does not clean up

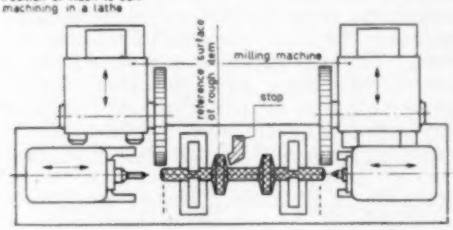

Fig 16: Machine for centring and cutting to length

circumstances how important is the co-operation between designer, forgemaster and machiner, we shall realize that the conditions of delivery by the manufacturer to the client largely depend on understanding on both sides that the best drop forging can only result from a joint effort. Hence it is absolutely necessary to found this understanding in the organization. Otherwise there can be danger of the large user of drop forgings tending to erect his own forge; he is of the opinion that the co-operation between the three participants is then easier, but he forgets that he must dispense with the special experience of those who, year in year out, have been concerned with nothing but the manufacture of drop forgings for very varied purposes.

This impression will be emphasized if we consider the special requirements which result from the individual manufacturing processes.

SPECIAL REQUIREMENTS FOR INDIVIDUAL FINISHING PROCESSES

Turning The additional machining allowance shall be so dimensioned that, at the most, two machine cuts are necessary. With parts which are to be hardened, the decarburized surface zone (0·1 . . . 0·3 mm), if present, must be removed with a single cut. Despite mis-matching, the turning tool must not just scratch the surface.

Mis-match and flash must be kept small, otherwise a serious variation of depth of cut, and thus the cutting force, will result; owing to the elastic resilience, this produces deviations from roundness of the machined item. Further, mis-match in the case of normal three-jaw chucks causes the workpiece not to lie in the axis of rotation.

Long turned parts, *i e* those which are turned between centres, must be tested for truth and, if necessary, straightened before centring. There is, for example, a difference whether an item is to be machined in a normal lathe or in a profile lathe; if the machining is automatic, then all these details must be carefully arranged in advance and all dimensions reliably maintained. In the first case one can machine the corners first, in the second case this is difficult. Aids forged on to the billet, *e g* centring eyes or flat tangs, assist the machining. With complicated forgings, before fixing the material allowances and the forging tolerances, one must know by what surfaces the forging is to be fixed in the jig and what is the order of machining.[5, 6]

Short machined parts are those which are turned in a chuck; these can often be grouped simply by providing the billet with an extension piece to suit the jig. Often the flash produces difficulties in holding, and it may be helpful to move the die joint.

Short turned items are usually held against one side. Their variations in thickness as a result of the wear of both halves of the die is therefore carried to the open side (fig 15). On this, therefore, first a thick, and then a thin cut is taken, on the opposite side only a thin cut; it can indeed be that at one point (*A*) the die is less worn and the workpiece is no longer cut. Hence it is often necessary to remove the workpieces during the process of manufacture and to correct them.

Boring To assist boring, surfaces which must be bored obliquely should have auxiliary surfaces upset on them which are at right-angles to the direction of boring.

Surfaces where the boring tool has material on only one side can be reinforced by additional corners which prevent the displacement of the tool; this is advantageous even if these must subsequently be removed.

Milling is the first operation if the milled surface serves as a reference surface for other surfaces. More often milling is a second operation after boring. The surface to be milled then sets the second plane of the workpiece.

It is true that cold stamping has obviated milling for many small parts, since the accuracy of stamping corresponds approximately to that of milling;

this is, the more stages of forging which can be used, and conversely (fig 9).

In respect of *deviations of shape*, the mis-match plays the main role; the author has previously reported on this.[1] In the meanwhile, forging machines, in particular hammers, have been made with much stiffer frames and more accurate guides[3] so that it has become easier to maintain small mis-match tolerances.

Under deviations of shape, we would also list flash which, for example, occurs with a new die (fig 10) if the trimming tool corresponds to the size of a worn die. The forged pieces must also be tested with respect to insufficient forging; it is well known that this can occur if the billet was placed in the die too cold, or if it was inaccurately inserted, or if the billet was cut off too short.

Thin forgings easily distort; they must be straightened and tested for straightness.

Deviations of position, *e g* of eyes with respect to one another, can likewise be produced by distortion; also by thermal stresses which occur on cooling or by stresses which occur on hardening, and can be the subsequent cause of non-permissible bending. Under certain circumstances, a straightening in the cold condition is permissible; fig 11 shows what difficulties can otherwise occur during machining.

The following *surface defects* can occur:

gross roughness as a result of heavily worn parts of the die,

laps, as a result of inaccurate forging,

marks from pick-up of loose scale (fig 12).

These faults are important for surfaces to be machined only if these serve for setting position before commencing machining; for example, surfaces which result from seriously worn parts of the die are unsuitable for this purpose (fig 13). Here again, co-operation between the designer and the forgemaster is important; the draughtsman should indicate setting and reference surfaces on the forging drawing so that attention may be paid to them during forging.

Also in respect of holding against surfaces having die draft the supplier can produce usable forgings only if he is informed of these facts (fig 14).[4]

Having established repeatedly from the above

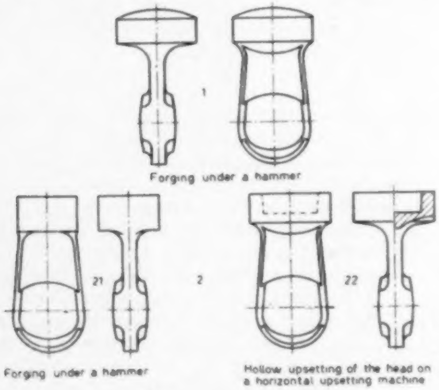

Fig 8
Better adaptation of the finished part by hot deformation in two directions

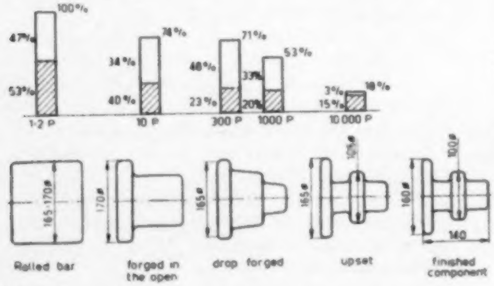

Fig 9
Material and machining costs with various forging methods

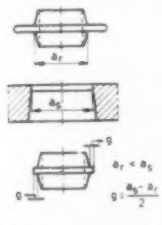

Fig 10
Flash due to too large flashing cutter

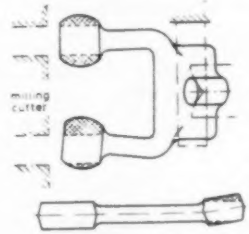

Fig 11
Positional deviation of a fork and a spanner due to distortion

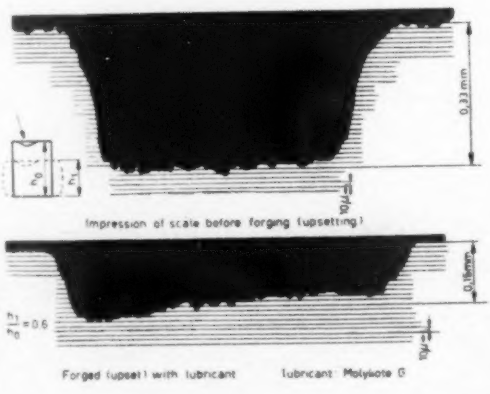

Fig 12
Surface profile before and after cold coining

mation resistances BA and B′A′, and therefore the amounts of work expended, OAB and OA′B′, will be rather different. The stamp S (fig 18*b*) must therefore have an adequate spare working capacity; this effects an elastic deformation of the anvil A of height H. Since the spare working capacity of the stamp varies, the height H also varies, and thus the height *h* of the workpiece varies. This, however, also springs back differently, namely, according to fig 18*a* by BC and by B′C′; unfortunately, these two influences add. Furthermore, the surfaces F_o and F_m give elastically. Whether two eyes, E_1 and E_2, are to be at an equal height will depend on whether both are forged to the same extent and whether they are symmetrical to the central axis of the machine so that the stamp S has no turning moment.

It is not at all easy to achieve high pressing accuracy, but it is possible if the above points are taken into consideration.

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Forging cylindrical parts

THE INTENSIVE DEVELOPMENT of machine tools during recent years is remarkable for the extended production now possible in sizes previously undreamt of. The power of these machines and the cutting-speeds now attained make it possible to reach very high production figures.

But when we consider particularly the question of turning we find that the following difficulties, inherent in this method of machining, have still not been solved: (1) Wastage of metal, which has even increased, and requires a special service for removing cuttings; (2) necessity for a large stock of steel of all sizes; and (3) the fibres of the metal are cut, thus reducing the tensile strength of the work-pieces.

In order to allow a rational use of present methods of turning, the above difficulties must be eliminated or at least reduced. The solution would seem to lie in the use of work-pieces roughed out by forging, but the usual methods of forging, in their turn, show the following drawbacks, which limit their application: (1) Forging dies are very expensive and can only be justified if large quantities of parts are required; (2) machining of forgings is generally difficult, since out-of-rounds, irregular tolerances and cutting off fashes reduce very notably the life of the cutting tools.

As a solution of this problem it is clear that the production of a semi-automatic machine for forging cylindrical parts can be considered an important technical advance. This machine makes an appreciable reduction in the usual troubles met with both in turning and forging, as detailed above. It fulfils the conditions required to make it the indispensable auxiliary of high-production turning.

Production with this machine gives the following advantages: Forging is done to within plus or minus 0·3 mm ($\frac{1}{8}$ in.), which is equal to rough machining and makes a definite saving of steel.

Bearings are perfectly concentric and parts are perfectly round, thus allowing of minimum tolerances and easy and regular machining.

Very short forging times: forging passes are made with steps of 1·5 to 4 mm ($\frac{1}{16}$ in.—$\frac{5}{32}$ in.)/min.

Standard hammers are used for forging all diameters, thus reducing tooling costs to a minimum.

Time for setting and starting machine is very short, being about the same as for a turret lathe. Owing to this fact, small runs of parts can already be forged with advantage on this machine. The machine works automatically and the task of the operator is limited to putting the blank into position and withdrawing the work-piece after forging, as well as controlling production.

The semi-automatic machine for forging cylindrical parts, type SFR 363, works by means of three standard hammers which give blows at the rate of 500/min. The work-piece, gripped in a vice, revolves at 46 rev/min and moves vertically between the hammers to give the forged length required. Control of diameters and lengths is effected by means of stops fitted on drums in a similar way to that used on turret lathes. The forging cycle is fully automatic and is hydraulically driven. The standard hammers of very simple design allow of all rounds being forged between 20 and 86 mm diameter ($\frac{3}{4}$ in.—$3\frac{3}{8}$ in.). For blanks can be used bars up to 100 mm (4 in.) dia. Forgings can be made up to 1,100 mm (44 in.) long and, with special templates, tapers can be forged up to 3° taper.

The increasing use of expensive high-alloy steels in all branches of industry makes it of prime importance to economize in steel. The arguments detailed above suggest that turning will be done more and more with work-pieces rough forged on semi-automatic machine for forging cylindrical parts.

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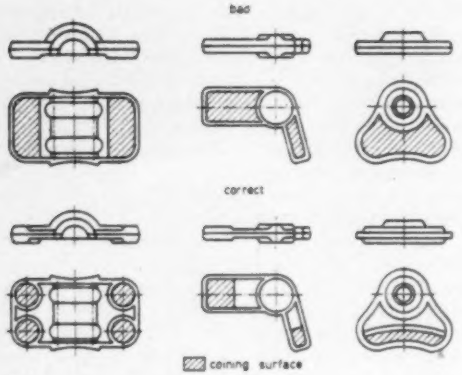


Fig 17
Formation of coined surfaces on drop-forged items

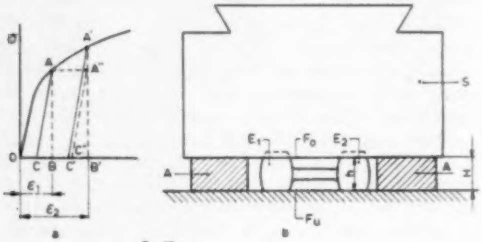


Fig 18
Coining of drop forging to size

however, in most forges there is yet no accurate coining press.

For the machining of crankshafts, the crankshaft lathe and the crankshaft journal milling machine are in competition. In the latter, the sensitivity concerning excess material is slight in the axial direction, since this only affects the width of the milling cutter and scarcely influences the cutting speed and the feed. In the circumferential direction, too, errors such as lack of roundness, mis-match and eccentricity are far less important than with a lathe, *i e* milling does not require so high an accuracy of forging.[7]

This is still more valid for milling to length, which among others occurs with long turned items. The double spindle milling and centring machine (fig 16) brings the forging to exact length and provides it with a correctly dimensioned centre. One is therefore relieved of the need for tolerance of the total length; it is immaterial to the milling machine whether it removes 2 mm or more cut.

Broaching The ideal first operation with drop-forged items is the external broach; it is a mass production method which suits the mass production of drop forgings. In many cases it has replaced milling. Despite higher investment and tool costs, this method is economic, since it provides rough machining and fine machining in one stroke.

Here it is important to maintain the machining allowances and forging tolerances as small as possible, since the number of teeth of the broaching tool, and thus its length, and the size of the machine, depend directly on the thickness of the layer to be removed.

For the machining of round parts, *e g* gear blanks, the internal broaching can also be done economically if the hot-pierced forging has a hole which is central and is cylindrical within small diametrical tolerances.

From this section it is very clear that the requirements in practice will not be met if one has only one or two series of tolerances for drop forgings. Their number must be much larger according to the general scheme of I.S.A. Tolerances. For every shape, every quantity and every method of machining, the most favourable tolerance must be found. The economic criterion is always that the sum of the forging costs plus machining cost should be kept to the minimum. The individual drop-forging firms must then become accustomed to supply forgings to different users with a different series of tolerances according to the purpose. Conversely, a firm which obtains the same or similar forgings from different drop forges will expect them all to work inside the same tolerances.

Improvement by cold pressing

As earlier we drew attention to cold pressing as a competitive method of drop forging, we will here consider it as a combination with drop forging. Eyes can be given so good a surface by cold pressing that subsequent machining is superfluous; also accuracy of dimensions between pairs of surfaces can be obtained. If this is so, then cold pressing is much cheaper than turning or milling, and even cheaper than broaching. The fixing problem is obviated; the tool consists only of an upsetting stamp with one flat surface and is therefore cheap, and the working process requires only a few seconds. Therefore it is often advisable to press only the surface of the forging by which it is held in the jig.

The machine required for cold pressing is either a spindle press or a drop hammer. Forges are well accustomed to both. It is therefore reasonable that they rather than the machining shop should carry out the operation of cold pressing and hence supply 'drop forgings with cold-pressed surfaces.' Some examples are shown in fig 17.

The accuracy of thickness depends on several influences. Firstly, the thickness of the forged item is predominant; if it varies, so that a piece must be upset to the amount of ε_1 = OB (fig 18) and another to that of ε_2 = OB′, then the defor-

Series on heat treatment

Controlled atmospheres

P. F. HANCOCK, B A, F I M

The composition, properties, methods of generation and applications of both protective and chemically active controlled atmospheres were discussed by the author at the heat treatment of steel lectures given at the Wolverhampton and Staffordshire College of Technology. This is the seventh of these lectures to be published in this journal. Mr Hancock is technical director, Birlec Ltd

A CONTROLLED ATMOSPHERE may be defined as a furnace atmosphere whose composition and distribution are deliberately controlled, with a view to producing a desired effect on the material being treated. As so defined, controlled atmosphere applications fall broadly into two classes:

(*a*) *Protective*, in which the objective is to prevent or minimize oxidation, decarburization or other chemical change in the surface of the metal being treated, examples being bright annealing and normalizing of ferrous and non-ferrous materials, bright or clean hardening and tempering of steels, atmosphere annealing of blackheart malleable.

(*b*) *Chemically active*, in which a desired chemical change is brought about in the surface of the material or throughout its section, examples being carburizing and carbonitriding of steel components, decarburization-annealing of whiteheart malleable iron castings, and gas descaling of hot-rolled steels. Also properly included in this class are many other processes, such as nitriding, chromizing and bulk reduction of oxides for production of metal powders.

A few bright-annealing operations, and some hardening operations can be carried out in direct gas-fired furnaces, where the products of combustion form the atmosphere, provided this is controlled in a suitable manner. But most processes in both classes demand the use of a gas-tight furnace or muffle, from the chamber of which air, or combustion products resulting from the heating operation, are excluded, and into which a gas mixture of predetermined composition is inserted. This requirement restricts the furnace types which can be used to (a) externally heated muffle, (b) electric and (c) gas-fired radiant tube.

Controlled atmosphere processes of all types are rapidly gaining in favour today in the metallurgical industries, replacing the older processes involving open furnace treatment, and packing processes such as box carburizing.

Composition and properties

Controlled atmospheres consist generally of mixtures of gases, containing some or all of the constituents N_2, H_2, H_2O, CO, CO_2, CH_4. Traces of free oxygen and sulphur compounds are often also present as impurities, the quantity tolerated depending on the particular conditions of treatment, and the material being processed. Ammonia may be added, when nitriding or carbonitriding is to be carried out.

The properties of atmospheres depend on the proportions of these various gases, and more particularly on the relative proportions of the chemically active constituents.

Thus, in processes where protection against oxidation is the only consideration, *e.g.* bright annealing of low carbon steels, the important reactions are :

$$M + H_2O \rightleftharpoons MO + H_2$$
$$\text{and } M + CO_2 \rightleftharpoons MO + CO$$

The equilibrium constants of these reactions are respectively:

$$K_1 = \frac{pH_2}{pH_2O} \text{ and } K_2 = \frac{pCO}{pCO_2}$$

Thus, the oxidation/reduction potential depends on the ratios of percentage H_2 to percentage water vapour, and percentage CO to percentage CO_2, the actual required ratios depending on the oxide dissociation pressure of the particular metal (or

High-strength bolts

New fasteners for high-temperature applications

STEEL BOLTS that can hold together aircraft structures at 900°F and permit major advances in high-temperature structural design in other fields have been introduced by Standard Pressed Steel Co, of Jenkintown, Pennsylvania. Called Hi Tm 9 fasteners, they combine exceptional strength with temperature resistance.

At 900°F, the rates temperature of the new bolts, the fasteners have a minimum tensile strength of 170,000 lb/sq in., which is 50% more than the strength of stainless and alloy steel fasteners now used at this temperature.

Immediate applications for the bolts are to be seen in aircraft engines, power plant steam and gas turbines, some nuclear and chemical processes, particularly those where both high temperature and high stress or pressure conditions exist.

These fasteners may also solve the problem of how the piloted aircraft of Mach 3-4 speeds (2,100-2,700 m p h) will be held together. Skin temperatures at these speeds are too high for conventional high-strength aircraft bolting.

The company's development work on Hi Tm 9, which included the most extensive elevated temperature study of fasteners to date, indicates that 1,200°F fasteners with equally remarkable, though somewhat lesser, strength will soon be produced. Initial fasteners, called EWB Tm 9, are a 12-point external wrenching type of aircraft tension bolt used for airframe fastening. Diameter sizes will range from ¼ to 1½ in.

Hot-work die steel

The new fasteners are being made from VascoJet 1000, a 5% chromium hot-work die steel produced by Vanadium-Alloys Steel Co, of Latrobe, Pa. The hot-work steels have been used for years as tool and die material in hot forging and extrusion presses and similar equipment. VascoJet 1000 is a modification of a popular hot-work steel, called Hotform, that Vanadium-Alloys developed 24 years ago. The bolt material was selected after a year's research, in which metallurgists evaluated many likely high-temperature metals.

Tests on the EWB Tm 9 fasteners show that from an initial room temperature tensile strength of 220,000 lb/sq in. the fasteners still have a minimum of 170,000 lb/sq in. at 900°F. Similarly, room temperature shear strength of 140,000 drops only to 100,000 lb/sq in. at 900°F

The tensile strength of Hi Tm bolts at 900°F at 170,000 lb/sq in. is at least 50% greater than the typical tensile values of 95-100,000 lb/sq in. for the stainless steel bolts and 110-120,000 lb/sq in. for the alloy steel bolts used at these temperatures. The strongest bolts now used in aircraft have a minimum tensile requirement of 160,000 lb/sq in. and a shear strength requirement of 95,000 lb/sq in.

The S P S Laboratories' report reveals equally favourable results for the new bolts in stress-rupture tests and in fatigue, shear and tensile strength tests conducted both at elevated temperatures and at room temperature after soaking at elevated temperature. The temperature stability of the bolts was indicated by full retention of room temperature tensile strength of 220,000 lb/sq in. even after 100h soaking at 900°F.

Features of the new bolts contributing to their extra strength are: (1) A new design in the Hi R thread with larger than normal radius in the root of the thread which S P S developed last year for its Hi Psi fasteners. The larger root radius reduces stress concentrations at the weakest point of the thread.

(2) Diffused nickel-cadmium plating used instead of the conventional cadmium. This provides good corrosion and oxidation resistance up to 1,000°F.

(3) A special 12-point external wrenching Flexloc locknut for the EWN Tm 9 nut that develops the full mechanical properties of the bolt both at room and elevated temperatures.

TABLE I *EWB Tm 9 bolt*

	Room temperature	Tested at room temp after 100-h soaking at 900°F	Tested at 900°F
Ultimate tensile lb/sq in. minimum..	220,000	220,000	170,000
Yield strength lb/sq in. minimum..	185,000	185,000	140,000
Elongation in 4 dia % minimum (specimen)	10	10	16
Reduction of area % minimum (specimen)	35	35	50
Shear strength lb/sq in. minimum..	140,000	140,000	100,000
Stress rupture lb/sq in. for 100-h life			130,000
Fatigue strength lb/sq in. at 8,000,000 cycles 10% preload	80,000	55,000	80,000
Impact strength ft lb (Charpy) ..	18	18	23

(i) EXOTHERMIC GENERATORS By partial combustion of town's gas, or other hydrocarbon-containing fuel gas, at combustion ratios between 55% and 98% of complete combustion, in a combustion generator, followed by condensation of excess water vapour, a range of atmosphere compositions can be produced between about the following limits:

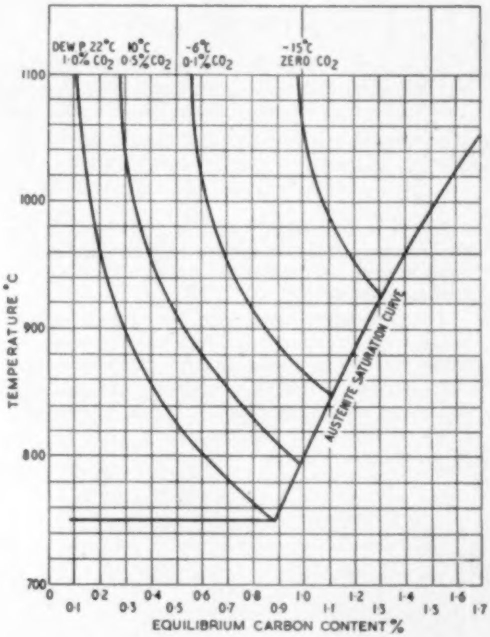
14 — 5% CO_2
1 — 14% CO
1 — 18% H_2
0 — 2% CH_4
Bal. N_2

In the simple generator (fig 1), the water vapour content depends on the temperature of the condenser cooling water, and may correspond to a dewpoint in the range 5—25°C. Refrigerators and/or dryers may be added to the plant to give dewpoints down to —40°C D P or lower.

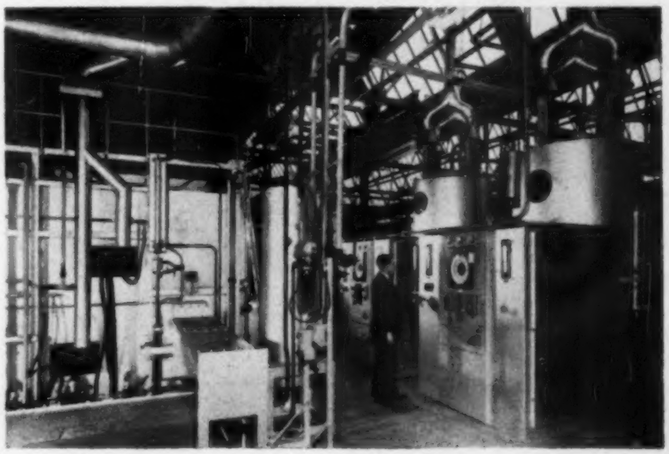
The reactions are exothermic, giving sufficient heat to maintain the reaction chamber temperature at the required minimum level of about 900°C. These atmospheres have a wide range of uses, in bright annealing non-ferrous metals and low-carbon steels, also furnace brazing and sintering. One or two stage sulphur removal is usual for non-ferrous applications but is rarely necessary for steels. These atmospheres have a low-carbon potential, due to the CO_2 content, thus they cannot generally be used where decarburization is of importance. To render non-decarburizing, the CO_2 must be removed as well as water vapour. Plant is available for this, using a regenerable solvent (diethanolamine), but is somewhat complex and costly, being generally suitable for fairly large installations only.

(ii) ENDOTHERMIC GENERATORS Reaction of hydrocarbon-containing fuel gases with air at much richer ratios (10—30% of complete combustion according to the type of gas) can be made to yield a product gas low in CO_2 and H_2O. Sufficient air is used only for completion of the reaction:

$$2\ CH_4 + O_2 \rightarrow 2\ CO + 4\ H_2$$



3 ABOVE *Carbon potential curves*



4 RIGHT *Endothermic generator installation*

constituent metals if an alloy), and on the temperature. It is always safest, in protective applications, for the equilibrium conditions to be met. But in practice kinetics may be the significant factor, in the sense that a composition which is somewhat off equilibrium may be tolerable, if the speed of the reaction is very slow at the temperature in question.

At temperatures above about 800°C, equilibrium is rapidly established in the reaction :

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \text{ (water-gas reaction).}$$

Thus, for a given CO/CO_2 ratio, the H_2/H_2O ratio will automatically adjust itself by the above reaction. It is often sufficient in practice, therefore, to control only one of these two ratios.

In processes on ferrous materials, in which carburization or decarburization or their prevention are involved, it is necessary to consider also the reactions:

$$2\,CO + 3\,Fe \rightleftharpoons CO_2 + Fe_3C \text{ (carbon in solution in iron)}$$
$$\text{and } CH_4 + 3\,Fe \rightleftharpoons 2\,H_2 + Fe_3C \text{ (,, ,, ,,)}$$

for which the equilibrium constants are:

$$K_3 = \frac{p^2CO}{pCO_2},\quad K_4 = \frac{pCH_4}{p^2H_2}$$

It must be noted that these constants involve the second power of the CO content, and the hydrogen content respectively. In assessing the carburizing/decarburizing action of an atmosphere, or the 'carbon potential,' as it is called, therefore, it is not enough to consider the ratio of CO to CO_2, or CH_4 to H_2. The total concentrations must also be taken into account.

Water vapour is also decarburizing by the reaction

$$H_2O + Fe_3C \rightleftharpoons H_2 + CO + 3\,Fe$$

but for reasons already discussed (water gas reaction), at higher temperatures this reaction need not be considered separately. At temperatures in the range 700—750°C, however, it is important.

Other reactions which must sometimes be considered are:

$$2\,CO \rightarrow CO_2 + C \text{ (soot)}$$
$$\text{and } CH_4 \rightarrow 2\,H_2 = C \text{ (soot)}$$

which may be important from the point of view of soot deposition, particularly in the presence of surfaces which have a catalytic influence on the reactions.

Sulphiding reactions such as:

$$H_2S + M \rightarrow H_2 + M\,S$$

may also be significant when using an atmosphere contaminated with sulphur, though of practical importance only with regard to non-ferrous materials.

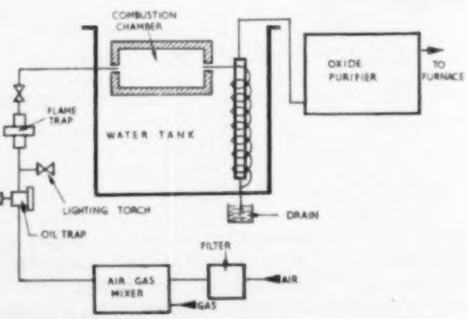
This is intended as only a brief introduction to the chemistry of controlled atmospheres. More detailed information is available in various standard treatises.[1, 2, 3]

Methods of generation

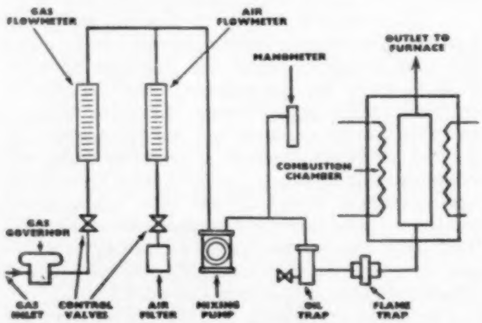
There are four principal sources of controlled atmospheres: (*a*) Town's gas, or other fuel gases, (*b*) ammonia, (*c*) charcoal, and (*d*) liquid organic mixtures (alcohol base, for carburizing).

The use of vacuum constitutes a fifth possibility (*e*).

(*a*) *Town's gas, and other fuel gases* This category is by far the most important, town's gas being cheap and readily available in most industrial localities. Bottled gases such as propane and butane form a suitable alternative, generally comparable in cost. Atmospheres are prepared from fuel gases by various processes of partial combustion, or cracking, with or without subsequent dehydration, CO_2 removal or other purification, to give a wide variety of product gases.



1 *Exothermic generator, diagrammatic*



2 *Endothermic generator, diagrammatic*

A similar range can be derived from methane, propane or butane, with slight compositional differences. The exothermic type can also be derived from kerosene, with the addition of a suitable vaporizer to the plant.

(*b*) ***Ammonia*** Anhydrous ammonia is available in liquid form in cylinders. By cracking over a catalyst (iron at 560°C, or nickel at 900°C), it can be split into its constituents:

$$2\ NH_3 \rightarrow N_2 + 3\ H_2$$

The gas as cracked has a dewpoint below —60°C and negligible impurities. The very high H_2/H_2O ratio gives maximum reducing power.

By partial combustion of either the raw ammonia or the cracked gas, a product of lower H_2 content can be obtained:

$$\frac{\substack{2\ NH_3 \\ N_2+3\ H_2}}{1\ \text{pt}} + \frac{4\ N_2+O_2}{1\ \text{pt air}} \rightarrow \frac{5\ N_2+H_2}{\substack{1\tfrac{1}{2}\ \text{pts product} \\ 17\%\ H_2}} + [2\ H_2O]$$

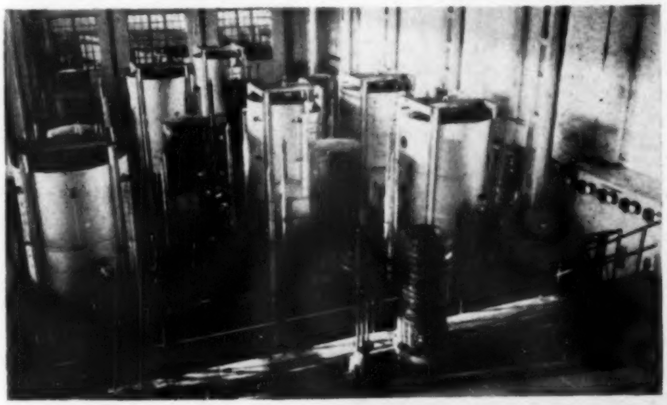
Dryers are necessary to give a high H_2/H_2O ratio in this case. The H_2 content can be varied between about 2% and 20%, by alteration of the combustion ratio. A typical plant is illustrated in fig 6.

Atmospheres from ammonia are of very high purity and cheaper than pure H_2, except for large quantities. The burnt gas forms an alternative to purified partially burnt town's gas for bright annealing of strip and wire, and the cracked gas is useful for bright-annealing stainless steels, sintering and other special applications.

(*c*) *Charcoal* Atmospheres may be produced from charcoal by combustion with air or flue gas. With air, the product is of composition:

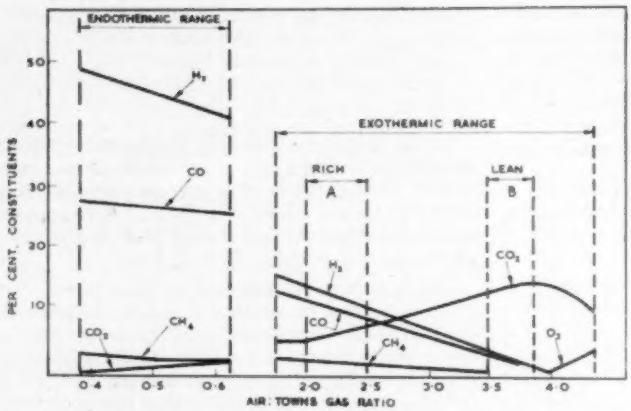
28 — 30% CO
3 — 1% CO_2
2 — 8% H_2
Traces CH_4

If dried, this gas is of moderately high carbon potential, but the required plant (fig 7) is cumbersome to operate and the product somewhat variable in composition. Charcoal plants have been largely



8 LEFT *Bell-type furnaces for steel strip*

9 RIGHT *Continuous stainless strip annealing furnace*



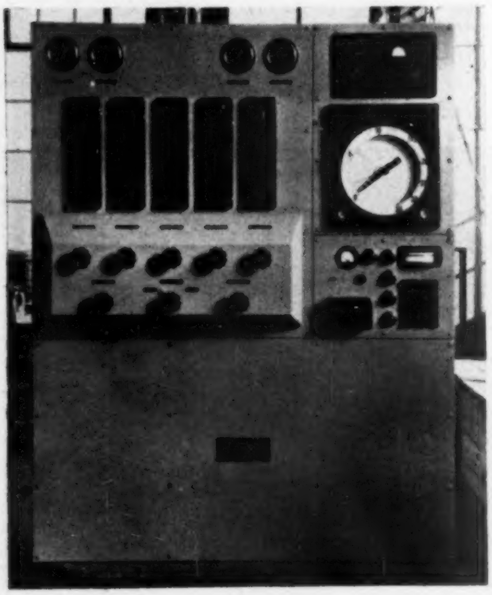
5 *Diagram of atmosphere compositions from town's gas*

A typical composition derived from town's gas is: 48% H_2, 22% CO, 1—2% CH_4, with 0—1% CO_2, D P —15°C to +20°C. The reaction is exothermic, but insufficiently so to maintain the reaction temperature. The plant, therefore, consists primarily of an externally heated retort and for this reason is termed 'endothermic.' A metal catalyst, usually nickel on a refractory carrier, is used to promote the reactions at as low a temperature as possible (1,000—1,100°C). The essentials of the plant are illustrated in fig 2.

This atmosphere has a high carbon potential, adjustable by variation of gas : air ratio. The carbon potential is inversely proportional to the CO_2 content or dewpoint, and control may be exercised by measurement of either of these quantities, as illustrated in fig 3.

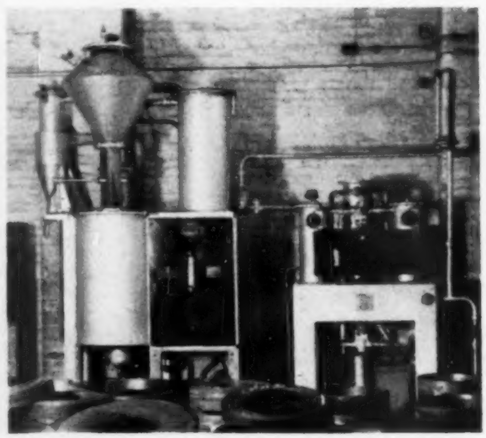
The endothermic generator finds a wide range of uses for heat treatment and brazing of carbon steels without decarburization, also for sintering applications, and as a base gas for gas carburizing and carbonitriding operations. An installation of two 2,000 cu ft/h generators, operating from propane, is illustrated in fig 4.

The whole range of atmospheres which can be produced from town's gas is illustrated in fig 5.



6 LEFT *Ammonia burner plant*

7 BELOW *Charcoal generator*



continuous bright hardening, employing this atmosphere is illustrated in fig 10.

For tempering operations, it is often unnecessary to employ atmospheres if the treatment temperature is low. If, however, it is desired to obtain a clean blue or black finish with tempering in the range 550—700°C, either the exothermic type or pure steam may be employed.

Furnace brazing For brazing of mild-steel assemblies a rich exothermic atmosphere is satisfactory. On high-strength carbon and alloy steels, however, where it is desirable to avoid decarburization, the endothermic type is preferred. Furnaces employed are usually of the continuous wire-mesh belt conveyor type as illustrated in fig 11. Stainless and heat-resisting steels require cracked ammonia, pure hydrogen or vacuum treatment in special furnaces.

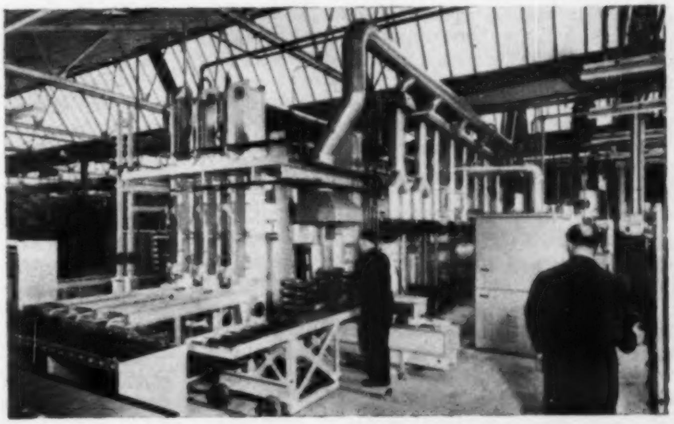
Powder metallurgy applications Sintering of iron and steel powder compacts is usually carried out in conveyor furnaces, of generally similar type to that illustrated in fig 11. Atmospheres must be of high reducing power, *i e* high $H_2 : H_2O$ ratio, and the choice is between cracked ammonia and endothermic, the latter being preferred when decarburization is to be avoided.

Gas carburizing, carbonitriding and related processes All processes in this category require an atmosphere of very high-carbon potential, in order to provide the driving force for the carburizing reaction. It is also desirable, particularly for medium and deep case carburizing operations, that the carbon potential should be adjustable to a lower level, to permit diffusion of the case to a controllable final carbon content.

For critical applications, a carrier gas of endothermic type, with provision for enrichment with a hydrocarbon gas—methane, propane or butane—is the usual choice. Alternatives which may also be employed, particularly for light cases, or where surface carbon need not be too closely controlled include the 'drip feed' type of atmosphere, where the atmosphere is formed directly in the furnace by pyrolysis of organic liquid mixtures, usually based on propyl or methyl alcohol. Town's gas, purified from objectionable constituents such as free oxygen, is also used. For carbo-nitriding operations, any of these atmospheres, with the addition of a proportion of raw ammonia gas, is suitable.

The more important types of gas-carburizing furnace are pit type, horizontal batch, and continu-

12 ABOVE *Pit gas-carburizing furnaces*



13 RIGHT *Continuous gas-carburizer*

superseded by endothermic generators for controlled carbon potential applications.

(*d*) *Liquid organics* Certain organic mixtures, particularly those based on alcohols, may be directly pyrolysed in the furnace to yield a gas of very high carbon potential, used particularly for gas-carburizing processes. The typical reaction may be illustrated in simplified form as:

$$C_3H_7OH \rightarrow 2\,CH_4 + CO$$

Propyl alcohol.

Commercial fluids are mostly based on methanol or propanol with addition of a hydrocarbon such as benzole or dipentene.

(*e*) *Vacuum* Soft vacuum (5—30 mm) is sometimes used for bright annealing of steel wire and strip in batch-type furnaces. High vacuum (micron range) is finding uses in brazing and annealing of stainless and heat-resisting alloys, and for sintering.

Applications of controlled atmospheres

Some of the more important applications will now be briefly described, together with the furnace types most commonly employed for the processes in question.

Bright annealing To ensure freedom from oxidation on plain carbon and low alloy steels, a H_2: H_2O ratio of 3: 1 or higher is necessary. This requirement may be met by rich exothermic atmosphere, or dried burnt ammonia, which are commonly used for bright annealing of low carbon steel products of mild and deep drawing types, in batch furnaces of pit or bell type (fig 8) and continuous furnaces of roller hearth and other types.

For processes involving long time cycles, *e.g.* the annealing of heavy coils and sheets in very large bell furnaces, a more nearly neutral atmosphere is generally preferred, to avoid blueing, etching or other surface effect during the long cooling cycle. For this purpose, lean exothermic atmosphere with the CO_2 and water vapour removed down to low levels is employed. The latter atmosphere is also used for carbon and alloy steels when decarburization must be avoided.

High-chromium steels of stainless and heat-resisting types form a special category, requiring a very high $H_2 : H_2O$ ratio to avoid formation of a surface film of chrome oxide. Carbon-containing gases must also be absent. Cracked ammonia or pure hydrogen of low dewpoint are generally employed, and to ensure maintenance of the required atmosphere purity in the furnace, the latter must usually have a metallic muffle forming the treatment chamber. A continuous pull-through furnace of this kind used for treatment of stainless steel wire or strip is illustrated in fig 9.

Heat treatment For hardening of carbon and alloy steel components, atmospheres of exothermic type are generally unsuitable, unless some degree of either oxidation or decarburization can be tolerated. To obtain true bright-hardening with complete absence of decarburization, endothermic atmosphere, with the carbon potential adjusted to suit the carbon content of the steel and the temperature of treatment, is the best choice.

A small furnace of shaker-hearth type, for

10 LEFT *Shaker-hearth bright-hardening furnace*

11 BELOW *Mesh-belt conveyor brazing furnace*

Controlled slack-quenching

An experiment being carried out at the metallurgical laboratory, U S National Bureau of Standards, in which an impact specimen just removed from furnace is held at opening in quenching fixture

THE U S NATIONAL BUREAU OF STANDARDS has recently developed an accurate method for measuring the effect of slack-quenching on the impact resistance of steel. (A slack-quenched steel is one that is cooled too slowly from its hardening temperature to ensure maximum hardness throughout. This effect cannot be avoided in unalloyed steel parts having large cross-sections because heat cannot be withdrawn from the interior fast enough to effect complete hardening. Thus microstructure and mechanical properties vary continuously throughout the metal.) Devised by M. R. Meyerson and S. J. Rosenberg[1] of the Bureau's thermal metallurgy laboratory, the procedure uses a Charpy (V-notch) impact specimen which has been immersion end-quenched. The quenching forms a series of planes having different but predictable microstructures and hardnesses depending on their distance from the quenched end. The depth of immersion and type of quenching medium used are predetermined from data obtained from an end-quenched Jominy specimen of the steel under study.

Little information has been available on the properties of slack-quenched steels. Consequently, manufacturers often substitute deep hardening alloy steels for the less expensive carbon steels to avoid risk. The Bureau's method of controlled slack-quenching should help to determine in what circumstances slack-quenched steels may be used. The method should lead to a broader understanding of the impact properties of steels as affected by microstructural variations, and may contribute to important savings in critical materials by reducing over-design.

Relationship with Jominy specimens

It was reasoned that impact specimens having slack-quenched structures might be prepared in a manner similar to that of Jominy specimens. A Jominy specimen is hardened by a jet end-quench. In theory it contains an infinite number of parallel planes and, assuming no surface cooling, each plane is cooled at a constant rate decreasing in speed with increasing distance from the quenched end. As a result, each plane has a different hardness and microstructure. A series of quenching and hardness tests were made on end-immersed impact specimens and Jominy specimens of the same steels. The microstructure and hardness existing at selected distances from the quenched ends were correlated. The data revealed a distinct relationship between hardness and structure at specific planes in the two types of specimens. These data have been reduced to graphical form for easy reference.

In studying impact properties of slack-quenched structures, a standard Jominy bar of the steel under investigation is first end-quenched according to the American Society for Testing Materials specifications. A hardness survey along the length of the

continued on previous page

ous pusher; two of these types are shown in figs 12 and 13.

Cost of controlled atmospheres

The data in Table I will give some guide to the relative cost per 1,000 cu ft of the principal types of controlled atmospheres, based on an arbitrary figure of 100 for town's gas.

TABLE I *Relative costs of controlled atmospheres*

	Type of atmosphere	Relative cost/ 100 cu ft
1.	Raw town's gas	100
2.	Lean exothermic from town's gas ..	25—30
3.	Rich exothermic from town's gas ..	40—50
4.	Lean exothermic with CO_2 and H_2O removed	30—40
5.	Endothermic from town's gas ..	80—120
6.	Cracked ammonia	400
7.	Burnt ammonia	200—270
8.	Charcoal producer gas	75—100

Atmospheres of types 2, 3, 4, 5 derived from bottled gases such as butane or propane are comparable in cost with the corresponding product from town's gas, where the cost per therm of the bottled gas is similar to town's gas.

Factors to be considered in application

In assessing the economics of a controlled atmosphere process, in comparison with a corresponding process carried out in open furnaces, or by packing methods, some or all of the following factors will need to be considered: (*a*) Technical advantages, in the form of a better or more consistent product; (*b*) elimination or reduction of after-processes, such as pickling, shot-blasting or finish grinding; and (*c*) lower heating, labour and material costs by elimination or reduction of dead weight.

Potential savings resulting from these factors must be weighed against the cost of the controlled atmosphere, and the additional capital expenditure for the atmosphere generating plant and the more complex furnace equipment generally necessary for its use.

References

(1) Ivor Jenkins, '[illegible]ontrolled atmospheres,' Chapman and Hall, 1946.
(2) 'Controlled [illegible]ospheres,' A S M Symposium, 1941.
(3) Hotchkiss & Webber, 'Protective atmospheres in industry,' Chapman and Hall, 1953.

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properties of triple alloy steels (those containing small amounts of nickel, chromium, and molybdenum).

The influence of varying carbon and alloy contents on the impact properties of slack-quenched structures has also been determined quantitatively.

(1) M. R. Meyerson and S. J. Rosenberg, 'Impact properties of slack-quenched steel,' *J. Research NBS*, 1957, **59**, (4), RP 2799.

Controlled slack-quenching

concluded from facing page

specimen is correlated with the microstructures. Once the desired hardness or structure is located in the Jominy bar and the distance from the quenched end established, the graph may be used. For example, one might want to study the impact properties of a specimen having the microstructure that exists $\frac{1}{2}$ in. from the quenched end of a Jominy bar. Reference to the graph indicates that an impact specimen immersed to $\frac{7}{8}$ in. in brine will have the desired hardness and structure at $1\frac{7}{16}$ in. from the immersed end. If the specimen is immersed only $\frac{3}{4}$ in., the desired structure will appear at $1\frac{1}{4}$ in. from the quenched end. In this case, either immersion depth may be used, since the notch used in impact tests must be located close to the centre of the specimen and at least 1·08 in. from the quenched end.

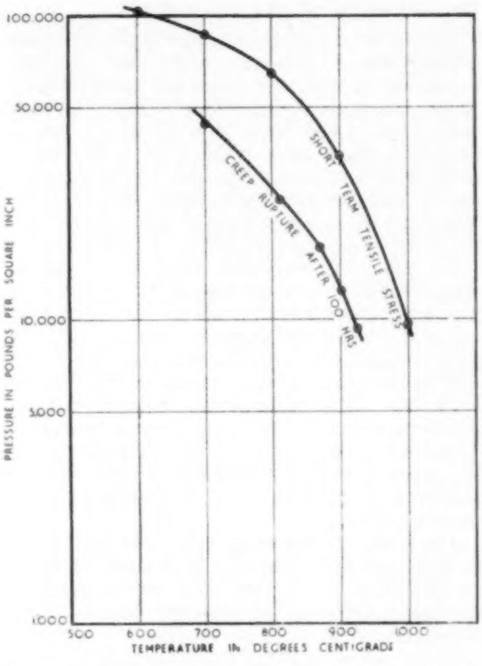
After quenching, the specimens may require a low-temperature stress relief (250°F) to inhibit subsequent cracking. Then the specimens are ground equally on all sides to remove any scaling and decarburization that may have occurred. A hardness survey made on one face locates the desired slack-quenched structure, and a standard V-notch is cut into the specimen at that point. Finally the ends of the specimen are cut off at a distance of 1·08 in. on each side of the notch. The impact resistance at that particular plane may then be determined by the Charpy impact test. Numerous hardness and metallographic surveys from centre to surface of impact specimens, after removal of the decarburized layer, have established the uniformity of hardness and microstructure in any plane above the immersion level and parallel to the quenched end.

Preparation of specimens

In making the impact specimens, they are first rough-machined to a size slightly larger than the standard impact specimen to allow for scaling and decarburization during heat treatment and to allow some latitude for locating the notch. One end of the specimen is drilled and tapped to accommodate a $\frac{1}{4}$-in. length of a 1/2-20 screw, 2 in. long. A washer, locked in a selected position by two nuts, supports the specimen in a quenching fixture. Thus a predetermined length of the specimen may be immersed vertically in a brine, water, or other quenching medium. The fixture is made of $\frac{1}{4}$-in. steel plate with drilled holes for eight specimens.

The method is suitable for the study of tempered as well as untempered slack-quenched structures.

Data obtained by the Bureau's method have established quantitatively the detrimental effect of various degrees of slack-quenching on the impact

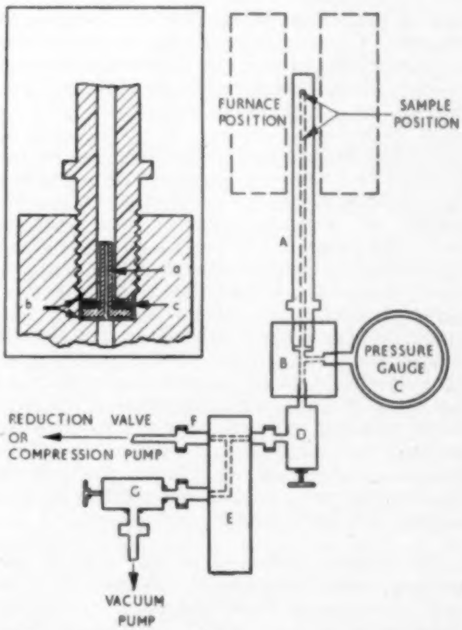


1 *Graph of bursting pressure of pressure vessel*

required pressures; also this restricted the heat conduction along the bomb and reduced its thermal capacity, allowing a faster rate of heating.

The diagram shows the arrangement of the bomb and gas system. Machined from a solid rod, the bomb (A) had an overall length of 15 in. and was drilled axially to a depth of 14⅝ in. to form a closed cylinder. At the open end the bomb had a 1 in. length of ½ in. dia B S P thread which screwed vertically into the junction block (B), with an 'Amagat'-type[2*] seal making a lead-washer joint which showed no tendency to leak at 6,000 lb/sq in. pressure although the joint was broken each time a sample was removed. A hexagonal collar welded to the bomb immediately above the threaded portion provided a spanner hold for firmly screwing the bomb into the junction block. This junction-block (B) consisted of a 2 in. dia by 3 in. long bar of Nimonic 90, with a machined flat face of 1 in. width in the vertical plane. The face had a tapped hole with ½ in. dia B S P thread to hold the pressure-gauge (C) which connected with the bomb aperture by a $\frac{1}{16}$ in. drill-hole. The outlet end of a needle valve (D) was screwed into the junction block end face, with access to the bomb. The inlet side of this valve was connected by screwed couplings to a nipple brazed into a brass block (E). This block acted as a pipe-line connector as well as being a means of rigidly clamping the bomb assembly to the base of the apparatus. A pipe-connecting nipple (F) brazed into the brass block provided an entry for gas into the system. This connected to the gas cylinder through either the reduction valve for lower pressures, or the compression pump for pressures above 2,000 lb/sq in. Another brazed nipple provided an outlet, through a needle valve (G), to a rotary pump for evacuating the system at the start of an experiment.

An electrical tube furnace, vertically suspended and counterbalanced, could be lowered over and around the bomb so that the top eight inches of the bomb were in the heated zone. The top four inches were at the maximum temperature. The temperature was uniform along this length, and was measured by a thermocouple secured by a nickel-chrome wire to the outside of the bomb at the position of the sample.



2 *Pressure-vessel assembly*

**The inset shows the 'Amagat' seal. A Nimonic insert (a) fits into the bore of the bomb and the counterbore (b) of the junction-block with 0·001 in. clearance. A drill-hole through the insert provides for flow of gas. Pressure on the lead washer forces it to squeeze against the counterbore wall, thus sealing the joint. Increased pressure improves the seal*

An apparatus for heating small samples

to elevated temperatures at high pressures

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An apparatus incorporating a pressure-vessel capable of withstanding an internal gas pressure of 6,000 lb/sq in. at a temperature of 950°C is described. Gas from cylinders is compressed by a pump to the pressure required, and the high temperature obtained by lowering a furnace over the end of the pressure-vessel which contains the sample

THE APPARATUS WAS ORIGINALLY BUILT for a study of the effects of pressure and temperature on gas bubbles and voids contained in solids. Although designed for this specific purpose the apparatus may be of use for the study of the effect of temperature and pressure upon reaction rates, solubilities, and physical properties of materials in general. As the pressure is applied by compressed gas it is hydrostatic, which very often has great advantages over pressure produced by a die-and-plunger method.

Although argon was chosen as the most suitable gas for use in the experiments, almost any other gas or even a liquid could be used provided there is no attack on the sample or the apparatus assembly. For normal requirements inert gases are preferable since they do not chemically attack materials; with gases such as oxygen or hydrogen safety precautions must be more stringent, because of the explosive risk involved.

Gas at pressures up to 2,000 lb/sq in. was supplied from a cylinder and regulated by a reduction valve; above 2,000 lb/sq in. the gas was compressed by a motorized piston-pump of robust design. This pump, having a compression ratio of 4 : 1, could easily compress to 6,000 lb/sq in. within its own cylinder, but three strokes of the piston were necessary to provide a pressure of 6,000 lb/sq in. in the pressure-vessel assembly. The total volume of gas was kept to a minimum by using $\frac{1}{8}$ in. bore copper tubing in the pipeline, reducing the vacant space in the valves with brass inserts, and filling the blank space in the pressure-vessel with an alumina rod. Pressures above 6,000 lb/sq in. could not be reliably attained because at this pressure the pump valve seatings developed leaks.

Description of apparatus

The pressure-vessel, hereafter designated the 'bomb,' was designed for operating at pressures up to 6,000 lb/sq in. and temperatures up to 1,000°C, requirements calling for a vessel made from a metal which would have a very low creep rate at the maximum test conditions and be highly resistant to corrosion. An alloy with the registered trade mark 'Nimonic 95' was chosen and the bomb designed on creep rupture figures supplied by the manufacturers[1], using the formula

$$\frac{P}{S} = \frac{R^2 - r^2}{R^2 + r^2}$$

which relates the maximum allowable hydrostatic pressure (P) within an infinite cylinder to its external and internal radii (R and r respectively), S being the maximum allowable fibre stress of the material of the cylinder at a given temperature. An internal diameter of $\frac{5}{16}$ in. and minimum wall thickness of 0·305 in. gave a design value for P of 12,200 lb/sq in. at 900°C and 9,400 lb/sq in. at 925°C. Creep figures above this temperature were not available but short-term tensile stress values for 1,000°C were used for design purposes, giving a bursting pressure (P_b) of 9,800 lb/sq in. based on the formula $P_b R = TS$ where T is the wall thickness, S the allowable tensile stress and R the external radius of the cylinder (fig 1).

X-ray photographs of the bomb were taken from three positions to check the concentricity of the bore, measure the minimum wall thickness, and examine the material for possible flaws.

The bore of the bomb was kept small in order to reduce the wall thickness necessary to contain the

Surface finish

Metallurgical and mechanical aspects

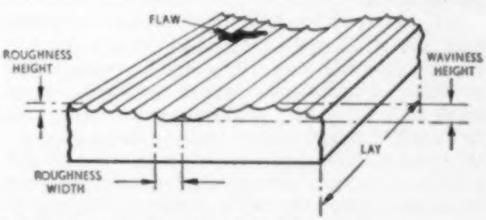
K. G. LEWIS, M Sc, F I M

The various expressions used in the study of surface finish are described, together with the more important machine and material variables which affect them. Particular attention is paid to chip formation and its influence on surface finish. The effect of metallographic structure is examined at length owing to its bearing on the formation of built-up-edge. Investigations into the mechanism underlying the formation of 'smear metal' are described and the various means for its removal compared, the comparison including an examination of the effect of cold-working on surface finish. This article by Mr Lewis, Principal of the Technical College, West Bromwich, will be concluded next month

WHILE A NUMBER OF RELATIONSHIPS have been established regarding surface finish, information relating generally to the subject is qualitative and concerned in the main with the effect of certain variables. The importance of surface finish and the effect of the properties of the material upon it have been emphasized by a number of authorities, but, in general, the same result cannot be achieved on different materials by any particular set of machining conditions and some metals can be brought to a high-quality surface finish more easily than others. Further, no assessment is normally made in machining calculations. The main considerations for maximum output are tool life and power consumption and these are affected particularly by machining variables, so that adjustment of the latter is the usual solution to production requirements. The qualitative aspect of surface finish is revealed by the fact that it is only at this late stage that further adjustment is made in the event of surface finish being unsatisfactory. At the same time, increased knowledge and experience of the effects of the operating machine and material variables can assist in reducing this somewhat random form of approach to a more controlled basis, albeit frequently qualitative in character.

Consideration of the instruments available for measuring surface finish is outside the scope of this review, but the great developments made in this field, together with the extensive research in the subject which has taken place during recent years, have now made it possible to define a given surface texture by parameters and simple indices. Specifications have been drawn up in the United States, and recently in this country, which give recommendations for methods of measurement and terminology of surface finish. In a proposed American standard[1] it has been suggested that the terms indicated in fig 1 be used. When it is remembered that the surface of an object is defined[2] as the boundary which separates that object from another substance, each of the terms acquires its own individual importance.

Roughness consists of finely spaced surface irregularities (less than $\frac{1}{32}$ inch)—in the present consideration, produced by the cutting action of the edges of a tool (or, by abrasive grains in the case of grinding) and by the feed of the machine tool. The average height of surface irregularities is a measure of roughness, but not a complete specification of the character of the irregularities.[3] Roughness may be considered as being superimposed on waviness and as not theoretically affecting the trueness of a surface. Waviness consists of surface irregularities which are of greater spacing (more than $\frac{1}{32}$ inch) than are those of roughness, such irregularities resulting from such items as deflections of the work or of the machine, vibrations, etc. Flaws are irregularities



1 *Characteristics of surface finish (Boulger)*

Method of test

The samples were enclosed in tantalum foil and held in position at the top of the bomb by the alumina rod already mentioned; the bomb was then screwed into place in the junction block (B) and the thermocouple secured. If the required pressure was less than 2,000 lb/sq in. the inlet to the bomb system at (F) was coupled to the reduction valve and thence to the gas cylinder; the cylinder valve was tightly closed, all other valves opened, and the system evacuated by a rotary pump to 10 microns pressure. The needle valve (G) was closed, thus isolating the rotary pump, and the cylinder valve opened so that the system was flushed with the gas being used. The cylinder valve was then closed and the valve (G) partially opened to allow the rotary pump to slowly evacuate the system. This procedure was repeated, the system finally evacuated of any remaining air and gas, and the bomb was ready for final pressurizing. This was done by isolating the rotary pump by closing the valve (G), opening the valve from the gas cylinder and releasing gas into the bomb through the reduction valve which was adjusted to give the required pressure. When the gauge (C) showed this pressure in the bomb the valve (D) was closed and the sample isolated in the bomb ready for heating under pressure.

Pressures in the range 2,000—6,000 lb/sq in. were obtained by connecting the compression pump to the system in place of the reduction valve. The system was evacuated, flushed, and evacuated again; the valve (D) was closed, gas released into the system and the inlet valve of the pump and the outlet valve of the cylinder closed. The motorized pump completed one forward stroke and compressed the gas in the pump cylinder, the pipeline, and the bomb. At the end of its stroke the pump automatically switched off and the outlet valve was manually closed, leaving the pipeline and bomb under increased pressure. The pump motor was reversed and the pump returned to its starting position. Because of the volume of gas in the system, three pump strokes were required to attain a pressure of 6,000 lb/sq in. in the bomb.

The furnace, preheated to the required temperature, took approximately 20 min from the time it was lowered over the bomb to raise the bomb temperature to 1,000°C. To keep the bomb pressure constant during this time, any build-up of gas pressure inside the bomb had to be released carefully through the valve (D) into the rest of the system. Conversely, at the end of the test period, more gas had to be pumped into the bomb to maintain constant pressure during cooling to room temperature.

Dependability of the apparatus

During the construction of the apparatus a main difficulty was the prevention of gas leakages at high pressures. In the early stages the original needle valves, with a metal spindle bearing against a metal seating, developed leaks due to scoring of the bearing surfaces after being used a few times. Replacements of these valves with ones in which the joint is made by pressing a non-rotating steel ball into a tapered seating overcame this difficulty and the valves have since been free of leakage.

Prevention of leaks from joints in the pipeline was partially solved by brazing as many connections as possible into the brass block (E). Of the remaining joints those of the gauge (C) and the valve (D) were permanently screwed down very tightly into soft washers on bearing surfaces in the junction block (B). Thus the only non-permanent joint in the bomb assembly was at the bottom face of the bomb itself. By employing an 'Amagat' seal at this point all leakage from the bomb was obviated and pressure could be maintained throughout the duration of a test.

The apparatus has so far been working at 6,000 lb/sq in. and 810°C for 540 h and from 1,200 to to 2,500 lb/sq in. at 1,000°C for 84 h without any apparent increase in the external diameter of the bomb.

References

(1) Henry Wiggins & Co Ltd, 'Short term creep tests on Nimonic 95.' Supplement to publication 459A. Table 12A (1956).
(2) Bridgman, P. W. 'Physics of high pressures,' 1949, p. 31.

Coil-spring research

Because of increased competition—rather than in spite of it—collaboration in the spring-making industry has become more important, especially so far as research is concerned.

This is the opinion of Mr R. Salter Bache, president of the Coil Spring Federation who, at the Federation's annual conference at Torquay recently, appealed for more members to support the industry's research organization.

Dealing with the activities of the research organization which last year was granted financial assistance by the Department of Scientific and Industrial Research for a further five years, he said that they were implementing the undertakings then given to D S I R by setting up new laboratories at Sheffield.

The first full year of work under Mr R. A. Haynes, the director of research, has been completed and a report on progress showed considerably increased activity.

The Technical Committee, under the chairmanship of Mr A. V. Jobling, who had recently succeeded Mr Harry Singleton, was giving its full attention to improving facilities still further. The main points were providing facilities for research; planning to operate within the limit of the Federation's income; and endeavouring to increase their income.

More space is now required to accommodate further research work, and the Federation is indebted to the British Iron and Steel Research Association for its co-operation in helping to provide the space.

TABLE I *Surface finishes for various applications. Aircraft Standards Committee*

Surface roughness, micro-inches, r m s	Production method	Recommended uses
500	Low-grade machined surface	For secondary parts not subject to stress concentration
250	Medium-machined or very roughly ground surface	For general use
100	Smoothly machined surface	For main or highly stressed parts
40	Very finely machined or medium-ground surface	For highly stressed parts, such as gear teeth
20	Finely ground, reamed, coarse honed, or lapped	For rotating shafts and bearings
10	Finest grinding, buffing, honing, or lapping	For interior surfaces of cylinders
5	Honed, lapped, or super-finished	For sliding surfaces where lubrication is not dependable

Effect of machining conditions

The surface finish produced at a given operation can be varied by changing the machining conditions. A number of factors exert influence in this respect, but speed, rake angle, tool condition and form and the magnitude of feed are all of outstanding importance. Before their individual effect can be interpreted, however, the question of chip formation must be thoroughly considered. Briefly, there are two main causes of surface roughness, namely, the fragments of built-up-edge which break away and are shed on the surface of the workpiece in the process of chip formation and the feed marks. Improvements in surface finish are achieved by counteracting either or both of these two effects, *i e*, by reducing either the height of the feed ridges or the size of the built-up-edge.

Chip formation and the formation of built-up-edge

The formation of one of three types of chip is normally possible in machining operations, the actual type being determined by the material of the workpiece and certain conditions of machining. The three types of chip have already been described[12] and are shown in outline in fig 2. Type 1 is the discontinuous or segmental chip, favourable conditions for the formation of which are relatively brittle material of workpiece, large chip thickness, low cutting speed and small rake angle. Depending on the degree of brittleness of the chip, the individual segments may split off at intervals in the zone of plastic deformation ahead of the tool. The pitch of the segments is a matter of importance,

2 LEFT *Discontinuous or segmental chip (type 1)*
CENTRE *Simple continuous chip (type 2)*
RIGHT *Continuous chip with built-up edge (type 3)*

a small pitch resulting in good surface finish of the work, but only obtainable when the previously mentioned favourable conditions apply.[13] Where this type of chip is associated with brittle materials —the usual state of affairs—the surface finish obtained is generally good, with reasonable tool life and low power consumption but, in the somewhat rare cases where this type of chip is produced in the machining of ductile materials, the finish will probably be poor with excessive tool wear.

The mechanics of type-1 chip formation are much more complex than for the simple or continuous type-2 chip,[14] the favourable conditions for which are, among others, ductile material, small chip thickness, high cutting speed, large rake angle, keen cutting edge and minimum opposition to chip flow over the tool face.[15] This type of chip is ideal from the standpoint of surface finish of the work and, in the case of ductile materials, the compressed region of the chip adjacent to the tool face passes off almost continuously and flows away instead of adhering to the tool face.

In the case of those ductile materials which do not possess the degree of machinability necessary for the production of type-2 chips, a built-up-edge is formed adjacent to the tool face. In varying degree this type—the type-3 chip (continuous chip with built-up-edge)—is more often produced when machining many of the ductile materials with high-speed tools. According to Ernst[15] it is the high friction between the compressed layer and the tool face, assisted by the high specific pressure and the high temperature developed, that causes this layer in such instances to become anchored to the tool face and to form a built-up-edge, while the chip shears away from it and passes off above.

The compressed region must exist under all conditions, regardless of the type of chip formation,[16] passing off completely with the formation of individual chip segments in the case of type 1 and continuously with type 2, but remaining more or less attached to the tool in type 3. Under this last condition, the portion of the chip near the cutting edge is still continuous with the work, so that each increment of advance of the latter causes an addi-

occurring at one place, or, at infrequent intervals in the surface and more commonly consist of isolated scratches, ridges, cracks, checks, etc. The direction of the predominant surface pattern is known as the lay and is usually governed by the machining method used, *e g*, as in turning or grinding. A lapped surface, however, has no definite lay direction and is known as multi-directional (or, non-directional).[4]

Roughness height values may refer to measurements based on any of the following: (a) Root-mean square deviation (r m s) from the mean surface, generally recorded as ($h_{r\,m\,s}$); (b) arithmetical average deviation from the mean surface ($h_{a\,v}$); (c) average peak to valley height; and (d) maximum peak to valley height (h_{max}). Obviously, it is impossible to compare roughness height measurements given in accordance with the different systems.[5] As a result of these different methods of measurement, the practice has developed of assessing roughness (or, primary texture) normally in terms of r m s or centre-line average values and for the assessment of waviness (or, secondary texture) in terms of average peak to valley height values. When comparing the relative magnitudes of the two types of texture on any surface, therefore, it is essential to keep clearly in mind the difference between these bases of assessment.

The roughness width rating is the maximum permissible width of repetitive units of the dominant surface pattern.[4] Irregularities having widths up to and including the maximum roughness width specified, or (in the absence of specification), up to and including the width of the irregularities due to machining feed, constitute the basis for the roughness height specification. Waviness widths are specified directly in inches.

Smooth surfaces are generally more expensive to produce than are rough surfaces, but the smoothest finish may not always be the most desirable, so that the optimum surface finish for a component will depend upon the cost and the ultimate application. It may well be that all surfaces of a component do not require the same degree of finish and the original cast, forged or cold-rolled finish may be preferable over certain areas. Frequently, cases are met where a certain degree of roughness is advantageous.

On the other hand, for parts which are to be subjected to alternating stresses, a smooth finish is usually desirable, since very small notches, such as those comprising a 'rough surface,' act as stress-raisers.[6] The permissible mean stress in a part subject to alternating loads is determined by the yield strength and the endurance limit of the metal and the latter property is especially liable to be influenced by the surface condition of the part. This applies particularly to steels at the higher strength levels. The decrease in strength which accompanies increased roughness has been shown[7] and the example has been cited of a part, heat-treated to 335 B H N and surface-ground, which has a higher endurance limit than a similar part with a machined surface and a hardness of 500 B H N. At the same time, however, notice must be taken of what would appear to be the special case of titanium alloys, with regard to which, it has been contended,[8, 9] the influence of surface finish on fatigue strength has been exaggerated to an extent not found in other structural materials. The titanium alloys are relatively new materials and, undoubtedly, more detailed information regarding them is required. Further work,[10] however, has recently confirmed the previous contention to a great extent. While machining and finishing operations certainly produced a disturbed metal layer to a depth of 0·012—0·015 inch below the surface of two structural titanium alloys, the surface roughness, while influencing the fatigue strength of these alloys to some extent, does not seriously do so and, in any event, to a much less extent than does hardness, as the following developed relationship readily shows:

$$Z = 207\,X^{-(0.0284)}\,Y^{(1.017)}$$

in which

Z = fatigue limit in lb/sq in

X = r m s surface roughness (micro-inches) and

Y = Knoop surface hardness (100 gm load).

This equation can be written generally:

$$Z = KX^{-a}Y^{b}$$

in which K, a and b are constants of the material.

From the above results, it was found that surface roughness lowered the mean value of the fatigue limit more at high hardness values than at low. Also, grinding may produce a surface 'softer' than the original material. Attention has been drawn[11] to the importance of residual stresses, as affected by the processing operation, and of the lay, especially with reference to the circumferential surface irregularities or scratches which, in certain cases, will lower the fatigue properties much more than will axial scratches of the same depth and contour. In view of the results of these recent investigations, it is certain that greater attention will have to be paid to all attendant conditions.

Surface finish requirements depend upon the intended application and Table 1 shows the degree of finish considered desirable for a number of purposes.

It will be seen that the finest or smoothest surface finishes are only required for the most critical applications. The greater proportion of components produced by machining have surface roughness values above 50 micro-inches.

ficial in such cases. A large feed, however, is much more detrimental to surface finish than is a large depth of cut. Reduction of feed is beneficial, since the load between the chip and the tool becomes reduced, as well as the width of the basic finish roughness. The general result is readily apparent from fig 4. Since tool life is less sensitive to depth of cut than to feed, it is possible to effect a compromise between good tool life and good surface finish by combining a large depth of cut with a small feed.

The turning tests previously mentioned[18] also supplied valuable information on the effect of depth of cut and feed. The 0·1% carbon steel was shown to produce the lowest values of surface roughness for the lightest feed of 0·005 inch/rev, the values being 70 micro-inches r m s for a depth of cut of 0·01 inch, 85 for a depth of cut of $\frac{1}{16}$ inch and 100 for a depth of cut of $\frac{1}{8}$ inch. When the feed was increased to 0·02 inch/rev the surface quality was poor, ranging from 400 to 300 with the more shallow depths of cut.

It is obvious, therefore, that feed exerts a considerable influence on surface roughness, the best finish being obtained with the lighter feeds. Also, while the depth of cut did not affect surface quality to the same extent, the lighter cuts gave slightly better surface finish than do the heavier cuts. With the lightest feed, the 0·3% carbon steel showed a slightly inferior finish to the 0·1% carbon steel. The best surface finish for the former, however, was obtained with the heaviest cut. The best finish on both the soft and hard grades of aluminium was obtained with the shallowest cut and lightest feed, while the free-cutting brass and cast iron showed great influence of feed on surface quality, but only a slight influence due to depth of cut.

Semenov[21] has developed empirical equations for the relationship of surface finish with feed and depth of cut in the case of the turning of cast iron at 300 ft/min, using two different tool materials (cemented carbide and a cast titanium-molybdenum alloy) with identical results. For the tool conditions adopted, the following relationship between surface roughness and speed was obtained, the depth being held constant at 0·01 inch:

$$h_{rms} = 16{,}000f + 14,$$

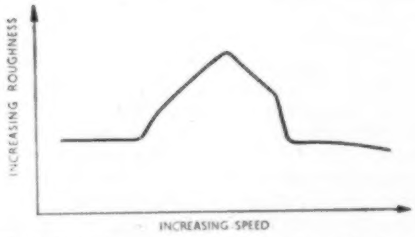
where h_{rms} = the r m s height of the surface irregularities (Profilometer).

When the feed was held constant at 0·002 inch/rev, the relation between surface finish and depth of cut, d, was

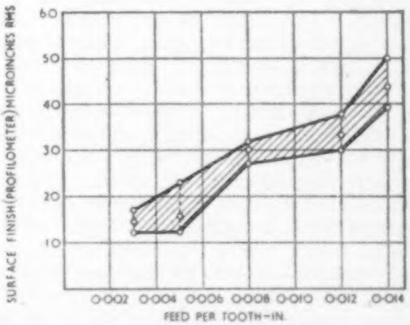
$$h_{rms} = 700d + 60$$

Rake angle The various types of rake angle have been shown to exert a definite effect on surface finish, but the particular type of rake angle demands consideration if only with reference to the mechanism underlying its specific effect, although it can be broadly stated that large positive rake angles tend to keep the size of the built-up-edge small.

The side-rake angle is the angle between the ground top face of the tool and the top or bottom plane of the tool, measured at right angles to the longitudinal axis.[22] A large side-rake angle results in a comparatively small built-up-edge, so allowing a smoother surface finish. It is, perhaps, unfortunate that this result is sometimes achieved through development of the very undesirable cratering phenomenon which can result in a large uncontrolled increase in rake angle, but with, of course, a corresponding heavy reduction in tool life. The side-rake angle, however, is dependent on a number of factors, some of which are opposed to one another. Of primary importance is the strength of the cutting-tool material and of the workpiece. In the former instance, larger side-rake angles can be used on high-speed steel tools than on carbide or on cast non-ferrous alloy tools owing to the greater strength of the steel. With high-strength workpiece materials, however, a much greater cutting pressure is exerted than with those of low tensile strength, so that side-rake angle is usually smaller when



3 *Effect of speed on roughness height of machined surface (Boulger)*



4 *Effect of feed on surface finish (Schmidt)*

tional piling up of compressed material in this region, the crystal grains of the material in this zone being elongated or distorted in a direction more or less parallel to the tool face. As this stationary accumulation of compressed material (or built-up-edge) becomes increasingly larger, the line of shear between it and the body of the chip on the one side and the work on the other moves increasingly further away from the cutting edge so that, as the built-up-edge increases, it also becomes more unstable, until a point is reached where failure occurs and fragments of the edge are torn off and escape both with the chip and the work.

The intermittent building up and breaking down of the forward end of the built-up-edge occurs at an extremely rapid rate, so that the surface of the finished work is covered with a multitude of fragments of ' built-up-edge.' These fragments are regarded as constituting the ' roughness ' of a machined surface, the degree of roughness being a function of the average size of the fragments and this size, in turn, being determined by the magnitude of the built-up-edge from which the fragments are torn. When the chip leaves the tool at the completion of the cut, it generally carries with it the remnant of built-up-edge which has been anchored to the cutting edge. The bond between this remnant and the tool face may be, under certain conditions, so strong that the remnant stays permanently attached to the tool.[17]

Just as machining conditions and the physical condition of the workpiece affect the type of chip, so they affect the size of the built-up-edge and, consequently, the surface finish. The larger the built-up-edge, the larger are the resultant fragments of built-up-edge which have been ironed into the workpiece and, hence, the rougher is the machined surface produced. It would appear that any condition leading to flow of the material of the workpiece tends to lead to increase in size of the built-up-edge. Thus, increased ductility (since it is essentially the ductile metals which are prone to strain-hardening) and depth of cut and, to some extent, decreased speed, will result in a larger built-up-edge. While all such factors must in the production sense be considered collectively, each item is of real importance with regard to its effect on surface finish and is worthy of individual study. The question of strain-hardening is discussed at greater length below.

Cutting speed While cutting at high speeds is generally considered to reduce the size of the built-up-edge and so to improve the surface finish, it would seem from Boulger's results (fig 3) that this (quite appreciable) effect is only exerted after a certain speed value has been attained. The degree of plastic flow necessary for the formation cannot be developed in the much reduced time available at higher cutting speeds. The result is a continuous chip without formation of a built-up-edge or, with the formation of one that is sufficiently small not to mar (at any rate, appreciably) the surface finish obtained by the particular machining operation. Thus, a continuous deformation of the metal ahead of the cutting edge takes place without rupture, followed by a smooth and swift flow of the chip along the tool face with low friction between chip and tool. This type of chip is the most desirable as far as surface finish, tool life and power consumption are concerned.

Actually, there is little further improvement in surface finish quality with increase in cutting speed once the built-up-edge has decreased to some insignificant size. The critical speed value at which this effect takes place is generally of the order of 300 to 500 ft/min, but it can vary considerably, depending on the material of the workpiece and of the tool, tool form, cutting fluid used, etc. This feature was well illustrated in turning tests on six different metals, using a standard tool operating at 0·020 inch/rev and a depth of cut of $\frac{1}{16}$ inch, surface roughness being determined as the cutting speed was changed from 25 ft/min to 450 ft/min.[18] At the lowest speed, the surface roughness was the poorest in the case of all metals, ranging from 500 to 225 micro-inches, r m s, the values being 500 for soft aluminium, 400 for two separate steels, 300 for cast iron, 250 for ' hard ' aluminium (24S-T) and 225 for free-cutting brass. At 250 ft/min the highest roughness was 300 r m s for cold-finished mild steel, followed by 275 for soft aluminium and approximately 200 for the less ductile materials—free-cutting brass, hard aluminium and a 0·3% carbon steel. At 350 ft/min, the surface roughness varied from 250 to 200 micro-inches, r m s, and this appeared to be the best finish obtainable for the group of materials under the cutting conditions already described. A separate series of facing tests[19] on normalized and annealed discs of 0·3% carbon steel, using cemented carbide tools, showed surface quality to be poorest at the lowest speed and best at the highest speed for all the cutting fluids used. The surface quality at the highest speed appeared to be much the same for four cutting conditions—dry and with three different cutting oils. Intermediate speed ranges gave increasing finish with increase in speed. It would seem that the improvement due to cutting fluid is at low speeds, *e g*, as in tapping.

Dimensions of cut—feed and depth of cut The size of the chip cross-sectional area has a marked effect on surface finish, being poor with a large cut and good in the case of a small cut.[20] This is a state of affairs in opposition to the effect of size of cut on tool life and power consumption, heavy cuts (combined with low cutting speeds) being bene-

must be placed on the back-rake angle if distortion is to be avoided in the machining of a long and slender shaft. Lastly, negative back rake protects the finishing point of a tool, due essentially to the cutting edge being put under compression (rather than being in shear or tension); the increase in included angle, so strengthening the weakest point; and the resistance to vibration and impact.

Mention must also be made of the true rake (known also as true side rake or cutting rake angle), since increase of this angle improves the surface finish considerably by reducing the size of the built-up-edge. The conventional side-rake angle is measured at right angles to the longitudinal axis of the tool, while the true side rake is measured at right angles to the side-cutting edge, but actually the cutting rake angle and the true side-rake angle are in theory nominally the same. Basically, however, the cutting rake angle is created by the combined affect of the side rake, back rake and side cutting edge angles. Its importance lies in that it determines the cutting action of the tool and controls the direction of chip flow. The necessity for understanding the function of the cutting rake angle, involving, as it does, three variable angles, has been duly emphasized:[26] ' . . . The true rake angle is defined as the actual slope of the top face . . . The chip flow is approximately in the direction of the actual slope of the tool face. The great significance which the true rake angle possesses in the machining process is due to the fact that it directly affects not only the cutting force but also the finish of the work and the tool life.' It must be added that rigidity of both the work and the tool is vital if improved surface finish is to be achieved by the employment of large rake angles.

Considerations of tool form A fine finish requires a fine feed unless a broad-nosed finishing tool is used. The lead angle (or, side cutting edge angle)—the angle between the side cutting edge and the longitudinal axis of the tool—is of importance in this respect since it increases the included angle at the finishing point of the tool and so strengthens this zone. Increase in the side cutting edge angle reduces chip thickness (and so the size of the built-up-edge) and reduces pressure on the cutting edge; it also enables chatter and vibration to be reduced and is an important factor in determining the direction of chip flow. All of these items bear, directly and indirectly, on the quality of finish of the machined surface, but the result in the case of the side cutting edge angle is variable since it is affected by other conditions.

Further consideration of the nose radius, however, becomes necessary, since, while its increase promotes improved surface finish, too large a nose radius means an excessive contact length between the cutting edge and the work, so that chatter can develop. The effect can be further increased by the production of a long, non-uniform chip—a small nose radius would produce a shorter chip—and, for this reason, a point angle, requiring less power, is to be preferred to a nose radius.[22] The mean purpose of the nose radius is to decrease the thickness of chip at and near the finishing point of the tool. Thus, pressure and heat generation on the cutting edge are reduced and it is in this way that improved surface finish results. The previously mentioned turning tests[18] on six different materials supply firm evidence that the least roughness is obtained when a tool having the largest nose radius is used. In these tests, the nose radius was varied from a sharp nose of zero radius to one of $\frac{1}{4}$ inch under the standard conditions described. Using the sharp radius, the surface roughness varied from 800 to 500 micro-inches r m s for all materials; from 400 to 100 for a $\frac{1}{16}$ inch nose radius; 200 to 60 for the $\frac{1}{8}$ inch nose radius and 175 to 60 for radii of $\frac{3}{16}$ inch and $\frac{1}{4}$ inch. The better finishes were obtained on the harder metals—' hard ' aluminium, free-cutting brass and cast iron—as would be expected.

The end cutting-edge angle also enters these considerations in that it decreases the nose angle and so weakens the tool. Finish deteriorates with increase in the end cutting-edge angle due to the height of the feed ridges on the surface of the workpiece becoming increased. A sharp nose radius can result, of course, in an irregular surface finish, but, in the case of finishing tools, surface finish can be improved by grinding a flat on the end cutting edge. This must not be too wide, however, otherwise too much of this cutting edge will be in contact with the work and chatter may result.

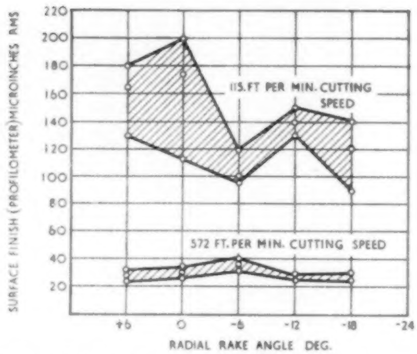
Briefly, tool form has a marked effect on surface finish and the correction of poor finish in practice is mostly effected by a change of one of the phases of tool form. In addition to the various aspects already mentioned, the only other angle of importance, the relief angle, exerts but a slight effect on surface finish.

Opposition to chip flow The smaller the opposition to chip flow the smaller the built-up-edge and, consequently, the better will be the surface finish. Opposition to chip flow is reduced to a minimum by maintaining a high polish on the tool face, by application of a lubricant to prevent the adhesion of the built-up-edge to the tool face, by the use of a cutting tool material (such as carbide) which has a comparatively low coefficient of friction and by ensuring that the grinding lines on the tool face lie in the direction of chip flow. The smoothness of the tool face is undoubtedly related to the friction developed between metal and tool. Thus, Merchant[27] has shown that the expression for the

machining the stronger materials. Again, small side-rake angles must be used when machining materials which develop considerable heat in order that the temperature in the neighbourhood of the cutting edge is not raised to an extent sufficient to soften the tool.[23] Obviously, carbides have a great advantage in this case. Finally, larger side-rake angles can be used on light feeds than on heavy feeds[22]—a state of affairs which complies with the feed requirements previously mentioned for obtaining superior surface finish.

Negative side-rake contributes indirectly in maintaining the quality of surface finish in that it strengthens the side-cutting edge, so protecting it from damage due to stress and impact. Under this rake condition, the pressure supporting area under the side cutting edge tends to be in compression rather than in shear, as in the case of positive side rake—the negative side-rake angle must be at least equal to the side relief angle in order to ensure that the side cutting area is in compression. The situation lends itself to the use of cemented carbides, with their outstanding compressive strength, and so to the employment of faster cutting speeds and to the machining of tougher materials. Against this sequence favouring improved surface finish, negative side-rake necessitates greater power consumption and so leads to higher temperatures at the cutting edge—again calling for the use of carbide with its superior red hardness. Power consumption and heat generation, however, can be reduced by combining positive side-rake with negative rake (in the form of a narrow land), so maintaining the strength-giving purpose of the negative side rake.[22]

In the case of milling cutters, side rake is usually referred to as radial rake. Schmidt[24] has reported on the results of milling tests with 2-bladed cutters and fly-cutters having 0° axial rake and various radial rake angles from 6° to 30° positive and from 0° to 30° negative. The true rake is, of course, the resultant of the radial and axial rakes (*i e*, a solid angle), but Schmidt's investigation relates essentially to the effect of radial rake. Cutting speeds ranged from 25 to 1,180 ft/min. Values of surface finish, as indicated in fig 5, were obtained from fly-cutting tests. It will be noted that there is a relatively small variation in finish due to changes in radial rake angle at a cutting speed of 572 ft/min, with much larger differences accompanying the rougher finish resulting from a lower cutting speed. When a multiple-toothed cutter was used, these surface finish effects could not be so readily observed (as when cutting with a single-bladed tool), owing to the variations in run-out, however small they may be, of the various blades. The results for a 2-bladed cutter, however, were found to agree within 70% with those shown in fig 5. Further



5 *Surface-finish readings obtained by profilometer (Schmidt)*

tests showed that modification of other cutter angles had but little effect, cutting speed and feed per tooth being invariably the determining factors with regard to surface finish, as has already been shown.

The back-rake angle is that between the top face of the tool and the top plane of the tool, but the effective back-rake angle is modified by the position of the finishing point of the tool in relation to the centre line of the work. In the case of this rake angle also, a number of reasons exist for its use. Firstly, it controls the direction of chip flow, more especially in the machining of ductile materials. In the case of a tool with a positive back rake, the chip flow is away from the machined surface. On the other hand, with a negative back rake, the chip flow is towards the work so that, in this case, the chip can touch the machined surface and so impair the surface quality. Means for chip-breaking offer the only solution here. Schmidt[24] also found blemishing of the machined surface for this reason when using cutters and the effect was observed to be most pronounced when the axial (back) rake angle had a greater negative value than the radial (side) angle.[25] Since tool life, however, was often improved with a negative axial rake, chip interference was eliminated by inclining the flutes in such a way that the chips were carried away from the machined surface. In turning operations, the introduction of chip-breakers enables the length of chip to be controlled so that it can be prevented from fouling the workpiece. For machining operations which produce relatively fine swarf, cutting fluid provides the most effective means of swarf control. When swarf trapped beneath a face-milling cutter marred the surface finish, however, the blades were set closer to the cutter face in order to prevent the chips from lodging in the spaces between the cutter body and the workpiece.

It must also be remembered that a definite limit

High-speed machining

New factory at Feltham

INDICATIVE OF THE TREND in industry, to segregate specialized technology and processes, is the establishment at Faggs Road, Feltham, of Messrs. Routing Ltd. This firm, as the name implies, specializes in the production of metal components by high-speed machining. It is believed to be the only firm engaged exclusively in this process. Routing Ltd, is an associate company of Morfax Ltd, Willow Lane, Mitcham, and was developed from the original routing department of the parent company, where for some four years routing development and tooling have been in progress.

The new factory is at present equipped with some 20 Wadkin routing machines of various types. In addition, there are special-purpose routing machines including a twin-operator skin-milling machine capable of handling plates 6 ft wide to an unlimited length. Supporting this installation are machines to handle tooling and templates manufactured for the routing production line. Blending and finishing equipment includes rumbling plants of various sizes and a Vacublast installation, the whole organization being adequately covered by a well-set-up inspection department.

A new factory building of some 18,000 sq ft is in course of erection at the rear of the existing premises. The new shop should be ready for occupation early in September, and will permit the expansion of plant and facilities warranted by existing production commitments.

Development of metal routing

Routing is the name given to high-speed milling. It was originally employed in the woodworking industry for the shaping of intricate parts and mouldings. Fundamentally the routing machine consists of a platen or work bench, a motor-driven spindle carrying a cutting tool. The arm supporting the driving head and cutter can be moved over the whole area of the work-piece. Material is removed by the action of the cutter rotating at high speed and biting into the surface or edge of the material according to the type of cutter used. A template or guide arrangement is fitted over the work-piece in such a manner that a loose collar or roller mounted on the driving spindle can be maintained in contact with the edge of the template by pressure applied to the head by the operator.

Bulkhead in high-tensile aluminium alloy being machined from solid billet

Routing is faster in operation than the band-saw, and imparts less stress in the material and has the further advantage that sheet materials can be profiled to template.

With the development of high-speed flight, designers were faced with the production of lighter structures capable of withstanding increased stresses. Attention was turned towards the high-tensile light alloys and the adoption of monocoque construction in airframe design. This break-away from orthodox composite fabrication called for an economical method of rapidly machining to fine limits, intricate sections and components from the solid billet.

The routing of components from the solid billet may appear at first sight to be wasteful and uneconomic. It will be appreciated, however, that, apart from physical considerations, the cost of material compared with that of the labour involved renders the process an economic one for, although the material is expensive, the speed of the process reduces the cost of labour and therefore the overall cost of manufacture.

Other applications of the process have been the development of skin-milling for aircraft and similar highly stressed sheet components. In this operation, the thickness of the sheet or skin is reduced over all areas except where stiffeners, ribs or attachment points are located. The result is a skin possessing integral stiffeners and reinforcement machined from the solid and having all changes of section evenly radiused.

coefficient of friction, μ, takes the approximate form

$$\mu = S/H + \tan \theta,$$

where S is the average shear strength of the area of contact;

H = the mean pressure surface hardness value for the softer of the two metals in contact;

S/H represents the adhesion; and

$\tan \theta$ represents the surface roughness, *i e*, the average slope of the ' hillsides ' of interlocking surface irregularities.

It then becomes evident that μ for the interface between the built-up-edge and the tool will be decreased if the tool face is made smoother, *i e*, if θ is made smaller.[28]

Material factors affecting surface finish

The degree of surface finish arising from a machining process can be considered in relation to the type of chip produced, as already discussed, or, with regard to certain basic variables.

The basic variables of metal-cutting processes Of the variables concerned in metal-cutting processes, only three are considered to be basic, namely, the shear strength, S_s, the machining constant, C, and the coefficient of friction, μ, and, of these, it is only the last which exerts a definite effect on surface finish. It can be related to other cutting values by the two following expressions:

$$\mu = \frac{F_t + F_c \tan \alpha}{F_c - F_t \tan \alpha}$$

$$\mu = \tan(C - 2\phi + \alpha),$$

where α = the rake angle of the tool measured in a plane perpendicular to its cutting edge;

ϕ = the shear angle (the angle between the shear plane and the surface being generated);

C is the machining constant (deg);

F_c = the cutting force (the force component acting in the direction of tool travel); and

F_t = the thrust force (the force component acting in a direction perpendicular to the surface generated).

If the friction developed between the chip and tool is high, the finish will be inferior and vice versa.[20]

While Merchant's expressions (above) have become more or less generally accepted, mention must be made of doubts arising from recent investigations regarding the use of the coefficient of friction in the evaluation of metal-cutting processes. Thus, Finnie and Shaw[29] considered that the coefficient did not portray adequately the friction process in metal cutting. More recently, the view has been expressed[30] that the significance of the coefficient of friction in the interpretation of metal-cutting phenomena has not been established conclusively and that tool performance may be more closely associated with the frictional force than with the coefficient. It is doubtful whether the assumption that a low coefficient of friction implies low tool temperature and long tool life can necessarily be upheld, since the coefficient, which is the ratio of the frictional force to the normal force on the tool face, can decrease (or increase) even when both forces increase (or decrease). This really confirms the previous view of Kronenberg,[31] who had pointed out that both force components can decrease and yet, if the normal force decreases more rapidly than the friction force, the coefficient will increase.

to be continued

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PEOPLE

Mr Lewis Chapman, C B E

PRESIDENT-ELECT of the British Iron and Steel Federation, **Mr Lewis Chapman** has had over 50 years' experience in the Sheffield special steel industries, having initially gone through the practical side of crucible and electric furnace steel melting, forging, rolling, treatment, etc. He was for some 25 years managing director of the B S A group steel interests in Sheffield, namely, Wm Jessop & Sons Ltd and J. J. Saville & Co Ltd, and now holds the positions of deputy chairman of the Birmingham Small Arms Co Ltd and chairman of Wm Jessop & Sons Ltd and High Speed Steel Alloys Ltd.

Mr Chapman has for many years occupied the chair of most of the Sheffield special steels associations, including the High Speed Steel Association and the Stailness Steel Association.

He started selling oversea before the first world war and has since travelled extensively, particularly in Europe, but also in America and Canada. He was awarded the C B E in the 1955 New Year Honours.

Election of **Sir William Scott** as chairman of the Finance Committee of the British Steel Castings Research Association was announced at the last annual general meeting of the association.

Sir William is managing director of Armstrong Whitworth (Metal Industries) Ltd and of Jarrow Metal Industries Ltd. He is also chairman of Armstrong Whitworth & Company (Pneumatic Tools) Ltd and a director of Jarrow Tube Works Ltd. He went to Tyneside in 1920 from the Armstrong Whitworth works in Manchester.

His knighthood—for political and public services in Jarrow—was announced in last year's Birthday Honours, and on September 30 he was the guest of honour at a dinner held at Newcastle upon Tyne at which representatives of industry, professional bodies, and technical education establishments in the north-east marked their appreciation of the honour conferred upon him.

Sir William played an important part in bringing back industry to Jarrow in the years of depression. He worked alongside 'Jarrow's benefactor,' the late Sir John Jarvis, father of Sir Adrian Jarvis, the present chairman of Armstrong Whitworth (Metal Industries).

Lord Halsbury will retire from the position of managing director of the National Research Development Corporation on March 31, 1959, to take up another appointment. In anticipation of the establishment of the corporation, he was appointed temporary adviser to the Board of Trade in May, 1949, and in the following month was made the Corporation's first managing director.

The corporation, which was established under the Development of Inventions Act, 1948, holds a portfolio of patents for Government, and some private inventions. It licenses them for industrial use and also arranges research and development programmes designed to demonstrate the practical value of previously unproved inventions considered by the corporation to be in the public interest, or to sponsor new inventions. In one particular field, that of the computer industry, it has made a considerable contribution to these ends.

Lord Halsbury, who was only 40 when he became managing director of N R D C, brought to this experimental organization a considerable experience in industry both on the research and on the commercial and administrative sides. During the war, at the research laboratories of Thos Firth & John Brown Ltd, Sheffield, he worked on the design of special steels for the blades of gas turbines and jet engines. From steel he turned to plastics, doing a great deal of valuable research into the production of suitable materials for long-playing records, as works manager for the Decca Record Co Ltd.

He was a member of the Advisory Council of the Committee of the Privy Council for Scientific and Industrial Research from 1949 to 1954 and is now a member of its Mechanical Engineering Research Board. He was elected president of the Institution of Production Engineers last year and is chairman of the National Institute of Industrial Psychology, chairman of the Science Museum Advisory Council, vice-president of the Parliamentary and Scientific Committee, vice-president of the Royal Institute of Philosophy, a governor of the Manchester College of Science and Technology, a member of the council of the Royal Society of Arts, and of the Manchester Joint Research Council.

Among tributes paid to **Mr J. W. Wardell** last week was one from Mr Richard Miles, chairman and managing director of Head, Wrightson & Co Ltd, Thorn .by-on-Tees. Mr Miles said of Mr Wardell that his integrity and devotion of service had made a great contribution to the present position of the company.

Mr Wardell, who is well known as a leading ore-preparation engineer, joined the firm as an apprentice in 1913 and left 10 years later to gain further experience with a London firm of consultants. In 1914 he joined a Siberian mining firm and was appointed assistant mill superintendent, but with the onset of the Russian Revolution, he left the country and returned to Britain, rejoining his old firm.

In 1925 he was appointed chief draughtsman and three years later manager, and subsequently general manager of the works. When, under a reorganization scheme, the forge division became Head Wrightson Stockton Forge Ltd, Mr Wardell was appointed managing director, a position he held until his retirement from active work in January. He retains his seat on the board.

To mark his half-century with the company, Mr Miles presented him with a silver teaset.

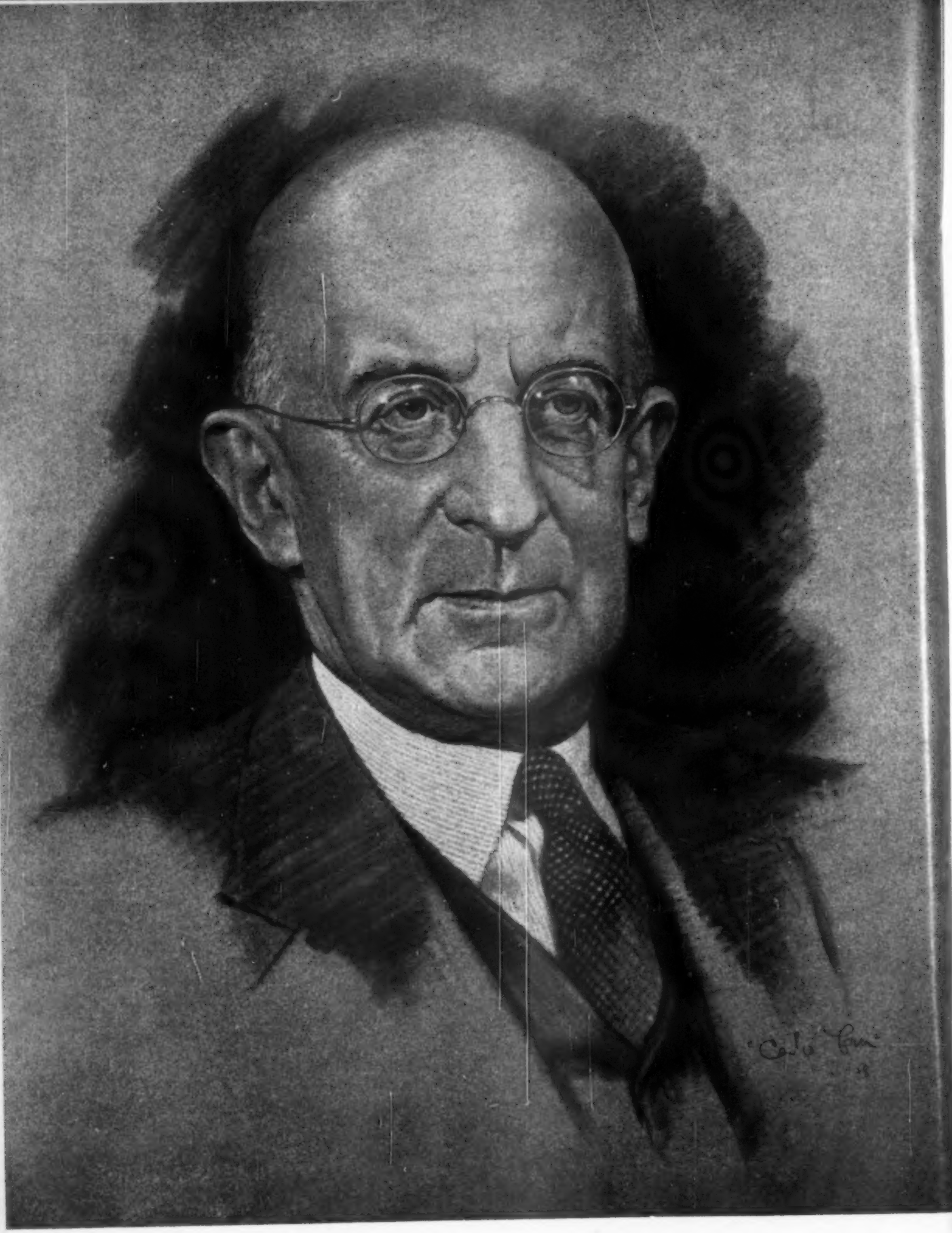
New Acheson appointments

Mr Edward A. Smith has been promoted to the position of assistant manager, European Operations. This senior executive position carries the responsibility of maintaining efficiently all operations of the various production units of Acheson Industries (Europe) Ltd in Britain and the Continent.

Mr G. J. B. Davies has been appointed general manager of Acheson Dispersed Pigments Co, Dukinfield, Cheshire. This company, which specializes in the processing of pigments into synthetic resins, plasticizers and other media, is a Division of Acheson Industries (Europe) Ltd. Mr Davies was previously general manager of Acheson Colloiden N V, Scheemda (Gr), Netherlands.

Appointments to Acheson Colloids Ltd, a subsidiary of Acheson Industries (Europe) Ltd, are as follows:

Mr A. Cheney as sales manager. He and his staff will move shortly to the new Headquarter Offices of the company which are in one of the modern buildings that characterize the new City of Plymouth.



Mr Lewis Chapman, C B E

NEWS

Open days at M E R L

New facilities for metrology and heat transfer research

NEW AND EXTENSIVE FACILITIES for research into mechanisms and metrology and heat transfer are now available at the Mechanical Engineering Research Laboratory D S I R at East Kilbride, near Glasgow. Visitors to this year's open days at the laboratory were able to see current work in these fields.

The two new buildings were completed last year, and the metrology section is believed to be the best equipped of its kind in the world. It provides a service to industry and other Government departments, including the rest of the laboratory, for a wide range of precision engineering measurements.

To enable accuracy when checking engineering components to be of the highest degree, the metrology wing is virtually a building within a building. This is to guarantee strict temperature control. All exterior windows are double-glazed and fitted with venetian blinds and the test rooms are surrounded by a temperature-controlled corridor. Each test room is supplied with air at the standard temperature of 68 F through a system of ducting concealed in a false ceiling. The air-conditioning equipment includes heating and refrigeration with auto-control, and the floor is of polished hardwood blocks to minimize dust. The Standards room, for example, has a thick concrete base resting on a rubber mat so that vibration from other areas will not upset sensitive measurements.

Facilities in the Heat Division's new laboratory are equally impressive, and include large experimental bays and smaller physics-type laboratories. In order that research may be carried out effectively, it has been necessary to provide sources of heating and cooling on a large scale. A total power of 1,750 kVA is available and the voltage of a large proportion of the a c supply can be remotely controlled to give a smooth variation from zero to full output voltage. A Deuce digital computer is being installed, primarily for the Division's work on the preparation of tables of thermodynamic properties of technically important fluids. Research being undertaken by this Division includes basic heat transfer, applied heat transfer and applied thermodynamics.

The work of all other Divisions was also on show, and highlights included results of laboratory and field investigations on methods of measuring large rates of flow of liquids in pipes; work on the growth of fatigue cracks in metals; and investigations into the hot extrusion of rods in a hydraulic press and the cold impact extrusion of rods and tubular containers in a crank press.

Welding courses for nuclear energy

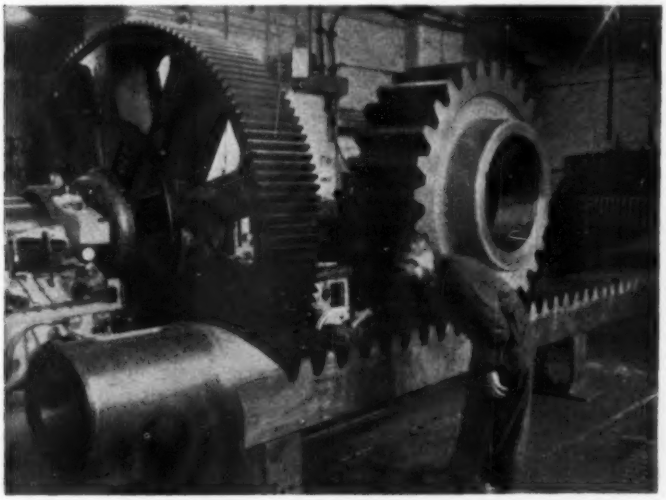
In view of the stringent specifications imposed on all welding for nuclear-energy projects, the John Thompson Group has inaugurated special courses for operators at its new welding school at Wolverhampton.

At present, men are receiving training in pipe welding in readiness for work at the Berkeley (Gloucester) nuclear-power station, now being built by A E I—John Thompson Nuclear Energy Co Ltd. Work on the site commenced in December 1957, and the work on pipe welding will commence in the near future.

In addition to basic courses for trainees, an improvers' course is also being held at the school. After receiving practical instruction, the operator must pass a series of tests to the Insurance Company specifications: these are macro examination and tongue-bend test. The operator is then sent to work under actual site conditions, and during the period he is on site he will undergo re-tests at regular intervals.

Equipment supplied to the Welding School by British Oxygen Gases Ltd includes D H high-pressure light-weight blowpipes, regulators and a dissolved acetylene manifold. Oxygen is supplied by direct pipeline from British Oxygen's factory in Wolverhampton. A special pipeline has been installed in the school and there are ten points throughout the building where oxygen and acetylene can be drawn-off as required.

Welding will be required at Berkeley on water and steam pipework for heat exchangers, tube connections



Supplied by the Jackson Division, Salford, of David Brown Industries Ltd, the machine-cut rack and pinion gears in this picture are for tilting 35-ton basic Bessemer converters in the Corby (Northants) plant of Stewarts & Lloyds Ltd.

The pinion, which weighed 5¼ tons in the finished state, was cast, machined and cut, while the 7¼-ton rack was cut from a solid forging.

Mr G. F. Henderson, as assistant sales manager. Mr Henderson will continue to operate from the company's Richmond office.

Mr T. Wint has been appointed sales engineer. He will be responsible for the North-East England territory and will operate from the company's Rochdale office.

Mr F. Gordon Kay has been elected to the board of directors of Acheson Colloids Ltd. Formerly sales manager of the company, he was promoted in 1957 to the position of manager, sales relations, of Acheson Industries (Europe) Ltd, the parent body for Acheson Colloids Ltd, Acheson Dispersed Pigments Co and Acheson Colloiden N V of Holland.

As manager, sales relations, of the parent body, he has been responsible for advice on sales and sales policy to the various units of the Acheson organization in Europe.

Mr Kay is much travelled and has completed two 22,000-mile business tours of South America since joining Acheson Industries (Europe) Ltd, in addition to considerable journeying in Europe.

Trained as an engineer, Mr Kay is an Associate Member of the Institution of Mechanical Engineers. He has in the past delivered various papers to learned societies on colloidal graphite.

Mr Kay has been with the Acheson organization for 34 years.

New names and addresses

The Birmingham branch of the English Electric Co Ltd has been moved from 75 New Street to larger premises at Pitmaston, Moseley, Birmingham, 13 (Telephone: SOUth 4021/5). The Domestic Appliance Sales section is also located in the new premises, but the Appliance Service Depot remains at 175 Tennant Street, Birmingham, 15.

Honeywell-Brown Ltd has changed its name to Honeywell Controls Ltd. At the same time, all head office departments and the London branch office moved from Perivale to a new building in Greenford. Its address is Ruislip Road East, Greenford, Middlesex (Waxlow 2333).

The new name identifies the company with its range of products—instrumentation, heating and air-conditioning controls, micro switches—and lines up with the names adopted by most overseas affiliates of the company.

The new building, which incorporates many modern aids to operating efficiency, puts all marketing functions —sales and service engineering, training school, export activities—and their executive direction, under one roof.

Metallurgical Engineers Ltd announces a change of address from Prince Rupert House to 5-15 Cromer Street, London, W C 1 (TERminus 8689).

The address of Climax Molybdenum Company of Europe Ltd will be 2 Cavendish Place, London, W 1 (MUSeum 8818) from September 1.

University professors at steel conference

Seventeen professors of science and engineering from British universities attended a four-day conference last month organized by the United Steel Companies Ltd on the relation of scientific research to production.

During their stay, the professors were in residence at University Hall, Sheffield, and visited United Steel's research and development department at Rotherham in addition to three of the company's steelmaking branches —Appleby-Frodingham Steel Co, Scunthorpe; Steel, Peech & Tozer, Rotherham; and Samuel Fox & Co Ltd, Stocksbridge.

An unusual feature of the conference was that research failures as well as successes were being presented for evaluation. Three examples of successful research investigations discussed concerned the prevention of breakouts from iron and steel furnaces, the development of low carbon bainitic steels and mechanization of drilling operations in steel sections and plates for structural uses.

Every opportunity was given to the visiting professors to participate in discussions with members of the company's staff and to pursue individual lines of enquiry.

At the annual meeting of the British Steel Founders' Association, **Dr Cyril John Dadswell** was elected chairman in succession to Mr G. M. Menzies, chairman and managing director of North British Steel Foundry Ltd.

Dr Dadswell, in addition to being on the board of the English Steel Corporation Ltd—he was elected in 1946—is managing director of the English Steel Castings Corporation Ltd, the English Steel Spring Corporation Ltd, and Davis & Lloyd (1955) Ltd, and a director of B S F A Holdings Ltd, Darlington Forge Ltd, and the English Steel Forge & Engineering Corporation Ltd.

He was for some years manager of the E S C Grimesthorpe foundry, and in 1941 was seconded to the Iron and Steel Control of the Ministry of Supply in connection with the building of mass-production foundries for track-link castings. In 1942 he went to the U S and Canada as

Dr C. J. Dadswell

chairman of the British armour mission to study, in particular, cast armour, and in 1943 returned to English Steel and took charge of the drop-forging department.

A past president of the Sheffield and district branch of the Institute of British Foundrymen, Dr Dadswell served as national president in 1952-53. He is also a director of the British Steel Castings Research Association.

Mr Colin Howell Kain, who has been elected vice-chairman of the B S F A, is managing director of Lake & Elliot Ltd, Braintree (Essex). Until 1954 he was joint managing director with Mr C. J. Lake. He is chairman and managing director of National Steel Foundry (1914) Ltd, and a director of Driver & Ling Ltd and the W-K-M Valve Company (Britain) Ltd. Mr Kain is a former chairman of the British Steel Castings Research Association, a Liveryman of the Worshipful Company of Founders, and a Freeman of the City of London.

British furnaces for U S

Wild-Barfield Electric Furnaces Ltd announces that the company has recently received from the United States an order for twenty-eight 750-lb capacity mains-frequency induction heated aluminium holding furnaces valued at nearly $300,000.

NEW PLANT

Forgings trimming press

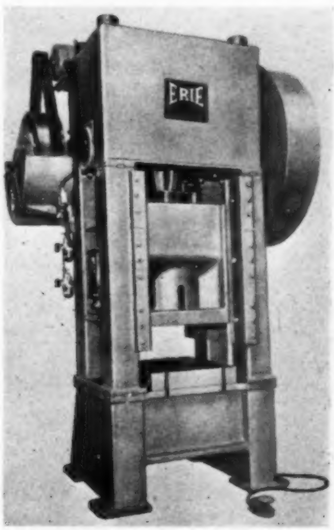
A new line of single-point, straight-side presses primarily designed for trimming forgings, but also useful for stamping and drawing operations, is announced by the Erie Foundry Co, Erie, Pennsylvania. The proportions of the press ram, bolster and stroke have been designed to J.I.C. press room standards; other J.I.C. standards have been followed where they apply. Trimming press users in the automotive and commercial forging field were consulted in order that this press would meet all their requirements.

The press frame is of four-piece construction, and uses pre-stressed strain rods for rigidity. The press features central forced lubrication, air counterbalance, and power ram adjustment. The lubricant is force-fed to all of the bronze bearings and guides. The pump for this system is mounted in a recessed position to protect it from damage.

The clutch is an air-operated, friction type which is engaged by compressed air and released by springs. The brake is a shoe type and is released by air and set by springs. Both the clutch and brake are designed to allow maximum air flow through them to keep them cool.

The long guide faces of the ram are fitted with bronze guide strips which can be replaced when they have been worn beyond the point where adjustment can take up the clearance. The guides for the ram are attached to the frame for easy removal should re-machining become necessary. Their length assures that the ram is never out of the guides at either extreme of the stroke.

The large-diameter ram adjusting barrel is securely guided in the ram to preserve accurate alignment. This adjustment can be made either manually or by motor. When motor drive is employed, limit switches restrict the travel of the adjustment.



1 *Forgings trimming press*

Electrical control for the press is recess-mounted on the right in the side housing. Windows are provided through the side housing on both sides to permit placement or removal of material from the sides of the press.

The press can be supplied in various speeds and strokes and in sizes from 150—600 tons. The 150-ton size is immediately available from factory stocks. Agents in the U K for Erie presses are Burton Griffiths & Co Ltd, Kitts Green, Birmingham.

Oxy-propane flame washing

A new flame-washing process has been developed by British Oxygen Gases Ltd to meet the need for a cheaper and more efficient method of removing excess metal from steel castings (fig 2).

The process is generally limited to castings which can be cut readily and safely by normal oxygen cutting methods. With castings which have a high carbon content, precautions normally taken for local heating applications (as with welding and cutting) should be adopted to avoid cracking and hardening. Flame washing is not effective when sand is encountered to any extent or for stainless or high-alloy steels. Powder washing should be used in these instances.

The flame-washing blowpipe is effective in areas which cannot easily be reached by hand grinding. It can be used to remove excess metal in the form of flashing, riser

2 *Shaping a crane hook by the flame-washing process*

within the exchangers, and the mains which carry steam to the turbo-alternator house. This installation of the reactor vessel, ducting and heat exchangers at Berkeley, is being carried out by Messrs John Thompson. The electrical contractors are A E I, who are providing the core of the reactor and the turbo-alternators. The civil contractors are John Laing & Son Ltd and Balfour-Beatty & Co Ltd.

Forming tube ends by the hot-spinning process

The use of the hot-spinning method to form the ends of tubes by a Cardiff engineering firm has proved to be two and a half times faster than conventional pressing methods and also cheaper by the same amount. The firm recently required an $8\frac{1}{2}$-in. diameter tube, 18 in. long, to be reduced at one end to a hole of $5\frac{7}{8}$ in. o d with its centre 0·35 in. off the centre line of the tube. Made from 7-gauge mild steel, the tube was rolled and seam welded and no thinning of the wall could be allowed during the reducing process.

The advice of British Oxygen Gases Ltd was sought and after investigation it was decided that the hot-spinning technique should be used in preference to pressing. After many experiments, the following procedure proved to be effective and is now being adopted.

The tube is set up 0·35 in. out of centre in the four-jaw chuck of a heavy centre lathe. A 20-jet oxy-acetylene burner is supported above the tube at such an angle that a zone $1\frac{3}{4}$ in. wide measured from the tube end is evenly heated. A $4\frac{1}{2}$-in. diameter roller with 30° taper is supported in the lathe tool post and set at an angle of 15° to the chuck centre line.

The tube is spun at 167 rev/min and heated by the burner for 40-45 sec before bringing up the roll to touch the tube end at the small diameter. The lead screw is then engaged and traversed for $1\frac{7}{8}$ in. This is the first forming operation and produces a 45° conical reduction on the end of the tube. The time for this operation is 8 sec. For the second operation, a roll is positioned and fed along for $\frac{1}{16}$ in. This shouldering operation takes 5 sec.

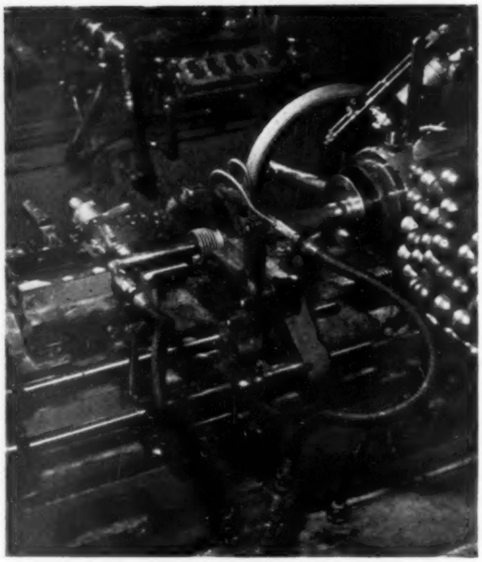
The forming process is finished off by changing the position of the second roll and engaging the cross-feed for a $\frac{1}{4}$ in. travel. The burner is switched off and the tube is cooled while spinning. The tube is then bored to size and end-faced.

This method of hot spinning has resulted in a wall thickness variation of only 0·0015 in., a far closer tolerance than that obtained by cold pressing. In view of the success of the process, a special machine is now being constructed to deal with many thousands of tubes on a production scale. This is being designed so that the rolls and cutting tools can be indexed automatically and the floor-to-floor time for each tube will be less than 3 min.

Mechanical spinning of metal bellows

New types of machines developed by design engineers of Smiths Motor Accessory Division have made possible a 20% rise in the output of thermostats from the Putney Vale factory of K.L.G. Sparking Plugs Ltd, part of the S M A group of companies.

Key to the increased production is a machine which enables the metal bellows of thermostats to be spun and fashioned mechanically and to a greater degree of controlled accuracy than was possible by manual methods. Equally important are other machines which deep-draw and 'iron' the brass stampings into thin-walled tubes, some 18 in. in length, and it is from these tubes that the bellows are automatically formed. The new method of drawing enables the tubes to be drawn 10% thinner—at 0·0045 in.—than was possible before, resulting in more sensitive bellows.



The bellows spinning machine

The highly skilled job of spinning the bellows was formerly done by operators using hand tools. Now, the new machine takes the tube and with a 'finger' insert pulls it outward against a guide which forms a series of convolutions of predetermined length and diameter. Two bellows are spun, in a matter of seconds, from one length of tube. When each bellows has been formed to a previously calculated size the machine cuts it off automatically.

To match the increased rate of output of bellows made possible by the new methods, semi-automation has been carried to the assembly of the complete thermostats. A conveyor belt carries all the component parts to the operators of each sub-assembly point. The operator removes whichever item is required from the conveyor and solders it in position by using a specially adapted high-frequency soldering unit. This same conveyor ensures that all the components are perfectly clean by passing through an electrolytic cleaning process.

From the moment the bellows come off their forming machine to the completion of the actual thermostat, very little 'handling' of the components is evident; the assembly cycle being that the bellows are first spin dried to remove surplus moisture and then annealed to relieve manufacturing stresses. The ends are cleaned and tinned on one of the many different rigs attached to the various high-frequency soldering units prior to having the 'bellows plates' and valve stem soldered in position.

The completed unit is placed on a special 'conveyorized' calibrating rig where it passes through the water-filled calibration tanks, the temperatures of which are electronically controlled to ± 1°C. During passage through these tanks the thermostat valve is finally soldered in position whilst still in water by high-frequency soldering.

Testing, also, is performed on the same conveyor. The thermostat is stressed to be beyond its normal operating temperature by virtually boiling it. From here the units are automatically ejected, visually inspected and packed for despatch.

pads, brackets and chill nails, and also to blend in core offsets. The equipment is simple—much the same as for normal cutting work except that a special curved nozzle is required—and propane is used as the fuel gas. An operator who is skilled in oxy-acetylene cutting can become proficient in the technique of flame washing after about a week's training.

The area which can be flame washed in one pass depends on how quickly the surface can be heated to ignition temperature. Two or more parallel passes may be necessary to remove riser pads larger than 3—4 in. across. For the majority of operations, gas consumptions are between 40 and 60 cu ft/h for propane and 400—600 cu ft/h for oxygen.

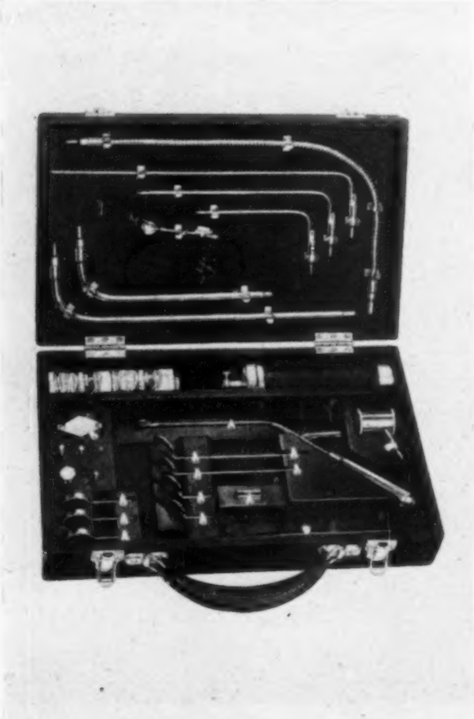
Although developed primarily for use in steel foundries, flame washing can be adapted to other types of work. The process is now being used in the manufacture of crane hooks. Approximate shapes are profile cut from thick steel plate and flame washing is used to shape the hook accurately from the square section. Previously, grinding and hammering were used for the final shaping.

Industrial inspection kit

The 'Ellispection' kit, manufactured and marketed by the Ellis Optical Co, Thornton Heath, Surrey, comprises a series of rigid and flexible probes with fixed and movable mirrors, magnifiers and midget battery-operated electric lights, the smallest of dia. $\frac{1}{8}$ in.

All parts are interchangeable and interlocking, thus one or more parts in any combination make it possible to probe, illuminate and inspect machinery, castings, dies, pipe assemblies, chemical plants, electronic valves and so many other types of plant or equipment.

As will be seen in the illustration, the compact kit is housed in a fitted, black hardwood case, compact and easy to carry. All metal parts are finished in durable nickel and two standard U 2-type torch batteries are the means of power and are housed in the battery handle.



3 *The 'Ellispection' kit*

Specimen preparation

The continuous rotation of the electrolyte in the Shandon electro-polisher prepares specimens for immediate microscopic examination.

The electrolyte, drawn through the centrifugal pump, is pumped through a series of holes so that it contacts the specimen as a constantly rotating, continuously renewed liquid column. This ensures a perfect polish and quality finish without flow lines. It eliminates cold working and false deformation structures and reduces specimen preparation to a mere routine instead of the highly skilled operation of mechanical polishing.

The polishing deck, mounted on rigid PVC, is a self-contained unit resting on the electrolyte tank and contains the pump, specimen clamp and electrolytic cell. The specially designed power supply has separate d c outputs and controls for manual and automatic polishing and etching. Additional output terminals provide facilities for beaker etching when required.

The pump is made from PVC and polythene, and all components in contact with the electrolyte are made from corrosion-resistant material.

Nucleonic thickness gauge

The first British-made four-channel nucleonic thickness gauge incorporates four electronic 'continuous balance' strip chart recorders to measure thicknesses of the order of 1/200th of an inch.

The material to be measured is passed between a radio-active source and a detector, which receives the radiation passed by the material. Variations in the thickness of the material cause minute and continuous variations in the intensity of radiation received at the detector. The highly sensitive 'continuous balance' potentiometer measures these changes, and indicates and records them either as material thickness or as weight per unit area.

Manufactured by the Baldwin Instrument Co Ltd, the instrument is installed on a machine producing rubber-coated cord for motor tyres. Two channels measure the thickness of the coating on each side of the cord (fig 4).

4 *Nucleonic thickness gauge*

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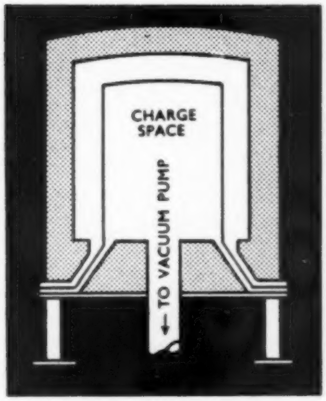
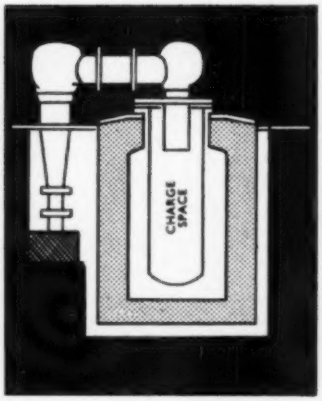
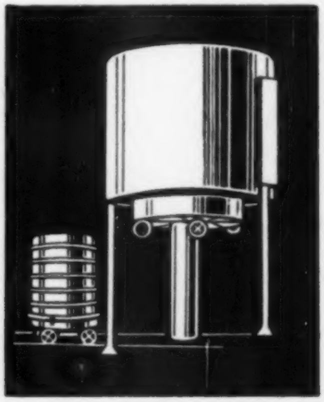


Efco-Edwards bell-type annealing furnace. The electrically heated furnace bell is lowered over a vacuum-tight retort, from which air is exhausted by the "Speedivac" pumping system.



Vacuum-type pit furnace. A vacuum-tight retort is lowered into a pit-type heating chamber. "Speedivac" pumping system and valves ensure rapid removal of air from the retort.



Elevator-type furnace. A vacuum-tight retort is lifted by a ram into a furnace bell raised above the floor. During the heating cycle the "Speedivac" pumping system produces the requisite vacuum in other charged retorts.

May we send you further details?

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